

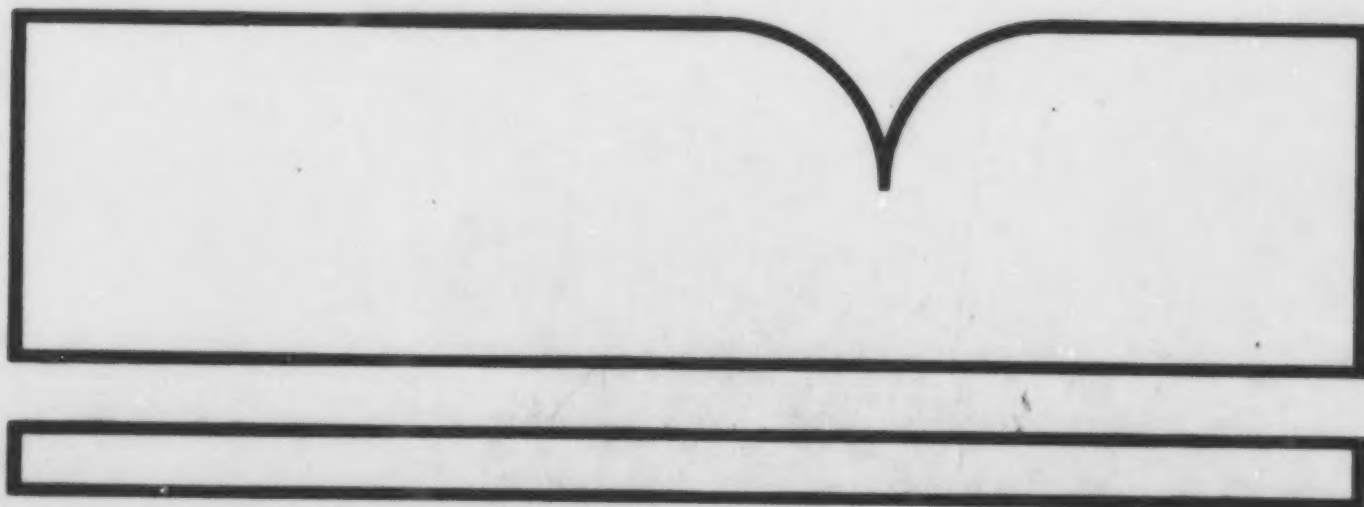
Design Optimization of the Chlorination Process
Volume I: Comparison of Optimized Pilot
System with Existing Full-Scale Systems

California Dept. of Health Services, Berkeley

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

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DESIGN OPTIMIZATION OF THE CHLORINATION PROCESS

VOLUME I

COMPARISON OF OPTIMIZED PILOT SYSTEM WITH EXISTING FULL-SCALE SYSTEMS

by

Endel Sepp and Paul Bao
California Department of Health Services
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Grant No. S803459

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16. ABSTRACT Parallel wastewater effluent chlorination studies were done on a mobile optimized chlorination pilot system and the full-scale system at eight different treatment plants. Disinfection efficiency was measured by total coliform enumeration and chlorine residual tests. Parallel flow-through fish bioassays were also conducted at each location. The objectives of the study were as follows: achievement of adequate disinfection with minimum use of chlorine; reduction of chlorine-induced toxicity; and writing of a design manual. At 7 of the 8 plants studied the optimized pilot plant achieved an equivalent level of disinfection with significantly lower chlorine dosage, in some cases more than 50% lower, than the full-scale plants. The pilot plant chlorine residuals were also lower by the same proportions. The reasons for the better pilot plant results were rapid initial mixing, improved chlorine control, and plug flow contact. In most cases the bacterial survival ratio could be expressed as a function of the product of chlorine residual and contact time. There appeared to be, however, a limiting contact time to which this relationship applied. The degree of coliform reduction obtained during initial mixing appeared to be a function of chlorine residual.		
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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The report that follows is a compilation of results from an in-depth study of chlorination system design deficiencies in modern wastewater treatment plants. It demonstrates that significant savings in operating costs can be effected by designing the chlorination facility properly from the start. This report will be used by design engineers and consultants responsible for designing new or upgrading existing facilities for municipalities needing to comply with chlorine residual and/or coliform discharge limitations.

Francis T. Mayo, Director
Municipal Environmental Research
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ABSTRACT

Parallel wastewater effluent chlorination studies were done on a mobile optimized chlorination pilot system and the full-scale system at eight different treatment plants. Disinfection efficiency was measured by total coliform enumeration and chlorine residual tests. Parallel flow-through fish bioassays were also conducted at each location. The objectives of the study were as follows: achievement of adequate disinfection with minimum use of chlorine; reduction of chlorine-induced toxicity; and writing of a design manual. At 7 of the 8 plants studied the optimized pilot plant achieved an equivalent level of disinfection with significantly lower chlorine dosage, in some cases more than 50% lower, than the full-scale plants. The pilot plant chlorine residuals were also lower by the same proportions. The reasons for the better pilot plant results were rapid initial mixing, improved chlorine control, and plug flow contact. The pilot chlorine dosages required to disinfect the various effluents to an MPN level of 2 per 100 ml with 60 minutes contact time ranged from 4 mg/l to 22 mg/l. Well treated domestic effluents required the lowest dosage, and unstable effluents and those containing industrial waste the highest. Nitrified effluents required relatively high chlorine dosages.

In most cases the bacterial survival ratio could be expressed as a function of the product of chlorine residual and contact time. There appeared to be, however, a limiting contact time to which this relationship applied. The degree of coliform reduction obtained during initial mixing appeared to be a function of chlorine residual. Good coliform reduction was observed in the full-scale mixers studied. Very poor correlation was observed between the membrane filter and multiple tube results in chlorinated effluents.

Overall, the pilot plant effluents were 42.9 percent less toxic to test fish than the full-scale effluents. In each case, the toxicity was primarily due to chlorine residual. The pilot plant effluents contained an average of 49.7 percent less chlorine residual than the full-scale effluents. Sulfur dioxide removed all chlorine-induced toxicity from the effluents.

This report was submitted in fulfillment of Grant No. S 803459 by the California State Departments of Health Services and Fish and Game, under the partial sponsorship of the Environmental Protection Agency. Work was completed as of September 1979.

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LIST OF ABBREVIATIONS

T	=	theoretical detention time = volume/flow rate
t_i	=	minimum contact time, i.e., time to the first appearance of tracer
t_m	=	modal time, i.e., time to the peak of the tracer curve
t_a	=	average contact time, i.e., time to the centroid of the tracer curve
d	=	dispersion number of a reactor
N_1	=	bacterial number at time t
N_0	=	initial bacterial number, in unchlorinated effluent
S	=	N_1/N_0 = bacterial survival ratio
R_0	=	chlorine residual immediately after mixing
L	=	total flow length of a chlorine contact tank
W	=	width of flow path in a chlorine contact tank
H	=	water depth in a chlorine contact tank
r	=	correlation coefficient
F	=	a statistic
C_c	=	unit cost of chlorine in \$/kg.
C_s	=	unit cost of SO_2 in \$/kg.
C_t	=	unit cost of chlorine contact chamber in $\$/m^3$
D	=	total chlorine demand in mg/l
DE	=	cost of dechlorination equipment
CE	=	cost of chlorination equipment
Q	=	effluent flow in m^3/d (mgd)
F&P	=	Fischer and Porter
W&T	=	Wallace & Tiernan
SO_2	=	Sulfur dioxide
DHS	=	Department of Health Services
DFG	=	Department of Fish and Game
V	=	Tank Volume

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The construction of the optimized chlorination pilot plant was performed by the Process Technology Company, Alameda, California.

Mr. George Clifford White, Consulting Engineer, provided valuable advice.

The computer analysis of data was done at the University of California Computer Center.

Dora Jang, Doreen Garfield and Cynthia Brumfield assisted with the typing.

William Kendall assisted with contracts and legal negotiations.

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SECTION 1

CONCLUSIONS AND RECOMMENDATIONS

1. At all of the seven wastewater treatment plants where comparative studies were made, the optimized pilot system used significantly less chlorine than the existing full-scale systems. In some cases the chlorine dosage saved by the optimized system was in excess of 50 percent. At these treatment plants the chlorine residuals in the pilot plant effluent were significantly lower than those in the full-scale effluents.
2. All plants studied, except South San Francisco, met their disinfection requirements. However, the chlorine dosages were often higher than needed to achieve the prescribed total coliform levels.
3. Overall, the optimized pilot plant effluents were 42.9 percent less toxic to test fish than full-scale effluents. The toxicity responses corresponded closely with the effluent chlorine residual levels. Overall, the pilot plant effluents contained 49.7 percent less chlorine residual than the full-scale effluents.
4. Dechlorination by sulfur dioxide removed all chlorine-induced toxicity from the effluents.
5. Tracer tests were necessary to assess adequately the performance of chlorine contact tanks. The use of the length/width ratio alone was found to be not sufficient.
6. Total coliform destruction during initial mixing was a function of chlorine residual; i.e., the higher the residual the higher the degree of destruction.
7. The coliform destruction observed in the full-scale chlorine mixers was greater than 99 percent.
8. The formula $N_1/N_0 = (RT/b)^n$ in good quality effluents adequately described the total coliform survival (N_1/N_0) — chlorine residual (R) — contact time (T) relationships. There appeared to be, however, a limit in contact time to which it applied. At contact times longer than 60 minutes the rate of bacterial kill slowed down. The slope and the intercept in the formula were different for each effluent. In poor quality effluents, or where water quality changed rapidly, the data exhibited a high degree of scatter.
9. The chlorine dosages and residuals required to disinfect the various effluents to the same total coliform level differed five-fold in pilot plant studies. The dosages required to disinfect the effluents to an MPN of 2 per 100 ml with 60 minutes contact varied from 4 mg/l to 22 mg/l in different effluents. The corresponding control residuals ranged from 2.8 mg/l to 11.5 mg/l. Poorer

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- quality effluents and those containing industrial wastes required higher chlorine dosages and residuals than good quality domestic effluents.
10. Nitrified effluents required higher chlorine dosages for disinfection than some of the non-nitrified effluents. The reason for this phenomenon remains unexplained.
11. The pilot plant chlorine control system performed significantly better than the full-scale systems, because of the following factors: a) very short loop time, b) adequate initial mixing, c) constant flow rate, d) instrument compatibility, and e) good operation and maintenance. In most cases, the pilot system maintained the control residual within the desired ± 0.5 mg/l range. It appears that poorly designed and/or operated chlorine control systems were responsible for a major portion of the excessive chlorine dosage used at most of the full-scale plants studied.
- The pilot chlorine contact tank also performed better than most of the full-scale tanks due to better plug flow and longer minimum contact time.
12. With effluents containing sludge and high levels of suspended solids the chlorine residual analyzer used clogged up and did not perform well.
13. There was very poor correlation between the total coliform results analyzed both by membrane filter and multiple tube procedures.
14. Significant cost savings can be effected by good design and operation of chlorination systems. However, if toxicity must be eliminated dechlorination is still necessary. The cost savings realized are mainly due to savings in chemical costs.
15. All except one of the sulfur dioxide dechlorination systems studied used feed-forward dosage control based on flow pacing and automatic chlorine residual measurement. Turbulent mixing provided at the point of application was adequate to effect removal of all chlorine residual from the effluent.
16. The design of wastewater chlorination facilities, following secondary or higher treatment, should include the following optimum features: a) Rapid initial mixing, b) reliable and well adjusted automatic chlorine residual control, and c) adequate contact time (at least 30 minutes at maximum flow) in a well designed contact tank approaching plug flow conditions.
17. Operator attendance is mandatory to keep the chlorine controls in order, including daily cleaning and calibration of the chlorine residual analyzers. Therefore, better operator training is necessary in chlorination system operation and maintenance.
18. Small treatment plants which cannot afford a closed loop chlorine control system should, as a minimum, install flow proportional control paced on effluent flow.
19. The use of sulfur dioxide as a dechlorinating agent requires automatic dosage control based on flow pacing, continuous chlorine residual measurement, and rapid initial mixing. No additional contact tanks are necessary.

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SECTION 2

INTRODUCTION

GENERAL

Increase in population and its mobility, along with much greater use of waters for recreation and water supply within the past two decades have greatly increased the opportunity for human exposure to wastewaters discharged to the environment. From a public health standpoint, former natural safeguards such as time, distance, and dilution have been reduced due to the large volumes of wastewater that are now discharged and the numerous points of use. Consequently, it is essential to provide effective disinfection of wastewaters prior to their release to the environment. In almost all cases this is accomplished by chlorination of the treated effluent. Residual toxicity in the wastewater has, in many instances, adversely affected aquatic life and since, in part, this toxicity has been associated with the chlorination of wastewater, there is a need to develop effective chlorination techniques which will maximize disinfection and minimize chlorine-induced toxicity.

The typical disinfection system which has been used at wastewater treatment plants does not provide efficient use of chlorine because of design and operational deficiencies. Treatment plant operators have attempted to meet stringent bacteriological requirements by changing the only process variable in the disinfection process over which they have direct control — the chlorine feed rate. Increased chlorine dosages may enable a waste discharger to meet disinfection requirements but the practice may result in the costly waste of chlorine.

The problems resulting from toxic discharges are increasing in magnitude and frequency (1,3). Four separate studies of the toxic effects of waste discharges to aquatic life were conducted in 1971 by the Michigan Department of Natural Resources at different municipal wastewater treatment plants (6). In every case, low amperometric chlorine residuals were toxic to the minnows and trout tested. High survival of test fish exposed to unchlorinated effluent indicated that the toxicity was due primarily to the residual chlorine. Downstream river reaches were rendered uninhabitable to many fish due to the discharge of chlorinated effluents.

The University of California, in a study for the California State Water Resources Control Board (7), reported that chlorine increased the toxicity of treated municipal wastewaters in all instances. The study concluded that: 1) chlorine-induced toxicity may be the largest single source of toxicity entering San Francisco Bay; 2) chlorine toxicity should be minimized through better process design to meet effluent bacteriological requirements with the lowest possible chlorine residuals; and 3) the optimization of the chlorination process, dechlorination, and alternative methods of disinfection for plants discharging into San Francisco Bay should be studied.

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Toxicity control is a water quality management objective that has been recognized by the California State Water Resources Control Board (8,9). Many regional boards have adopted discharge requirements in which toxicity limits or maximum chlorine concentration in the wastewater as well as a bacteriological requirement are specified. The disinfection systems available at most treatment facilities are not capable of producing a well disinfected effluent which is low in toxicity. Consequently, it has been necessary to install dechlorination facilities to remove chlorine residual prior to discharge.

This report is published in two volumes. Volume I covers the current chlorination studies. Volume II covers the toxicity determinations done by the Department of Fish and Game (21).

OBJECTIVES

The overall objective of the project was to develop a comprehensive manual of practice, based on thorough field study documentation, for the optimum design and operation of chlorine disinfection facilities which would insure effective disinfection with a minimum chlorine dosage. This manual of practice, which considers all available information on chlorination and dechlorination, is published as a separate volume (22).

The investigation aimed to assess the feasibility of achieving consistent and reliable disinfection with the lowest possible chlorine residual (and the concurrent reduction of toxicity) through improved chlorination process design.

Specific objectives were as follows:

- 1) Assess the efficacy of selected treatment plants in meeting existing disinfection standards as a function of effluent quality, initial mixing, residence time distribution, chlorine residual and process control;
- 2) Assess the toxicity concentrations of effluents as a function of chlorine residual and other parameters;
- 3) Assess the efficacy of a chlorination system of optimum design in providing adequate disinfection of effluents with minimum chlorine residuals at different contact times;
- 4) Compare the results from the optimized pilot plant to those of the full-scale plant in regard to disinfection efficiency, chlorine residuals and toxicity;
- 5) Assess the efficacy of sulfur dioxide dechlorination process under field conditions;
- 6) Compare the results of multiple tube and membrane filter techniques for coliform bacteria in disinfected effluents;
- 7) Identify cost savings achievable by optimum design.

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The first two years of the project were devoted primarily to the design and construction of a mobile optimized chlorination pilot plant and a fish bioassay laboratory, selection of 8 treatment plants for detailed field study, and preliminary field studies. The chlorination pilot plant was manufactured by a private contractor on a 13m (40-foot) long flatbed trailer. The bioassay laboratory was built by the Department of Fish and Game (DFG) in a laboratory trailer and equipped with continuous-flow aquaria and the necessary monitoring equipment. This laboratory is described in Volume II of this report (21). An existing mobile public health laboratory was provided by the Sanitation and Radiation Laboratory to conduct bacteriological and chemical analyses.

Main Field Study Program

Eight treatment plants were investigated for an average of four weeks each. The pilot plant was set up to receive unchlorinated final effluent and adjusted to the same coliform level as the existing plant. Two weeks at each site were devoted to the comparison of the pilot plant's performance to that of the full-scale plant. The bioassays were done at the same time. The remainder of the time was used for setting up equipment and special studies. Each comparative study consisted of the following:

- 1) Moving in and setting up the three mobile units, and adjustment of the pilot plant;
- 2) Two four-day flow-through fish bioassays on three simultaneous waste streams: unchlorinated effluent, chlorinated effluent, and chlorinated pilot plant effluent (the pilot plant was set to meet the same effluent MPN level as the full-scale plant);
- 3) Frequent sampling for chlorine residual, coliform bacteria and wastewater quality constituents, on both the pilot plant and full-scale plant;
- 4) Concurrent studies on the pilot plant to test the effect of different detention times;
- 5) Monitoring plant flows and chlorine feed rates;
- 6) Monitoring the chlorinator and calibration of the residual analyzer on the pilot plant.

Special Studies

In conjunction with the main program described above the following special studies were made.

Distribution of Residence Times. - In the past, little attention has been given to the design of chlorine contact tanks and it has been common practice to use only the nominal mean residence time (theoretical detention time), T , (tank volume divided

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by the flow rate) as a parameter in assessing process efficiency. However, the distribution of residence times and disinfection efficiency may differ appreciably in tanks of different geometrical configuration, even if the tank volumes and flow rates are identical. The "residence time" discussed herein, which refers to the hydraulic residence of a fluid, is identical to the more common term "chlorine contact time."

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In practice, the residence time distribution and the bacterial reduction provided by continuous flow tanks may vary between the extreme limits of ideal plug flow and completely mixed conditions. Collins, Selleck and White (10) have demonstrated that the coliform reduction by these two systems can differ by four orders of magnitude in different contact tanks. Effective design should approach the ideal plug-flow performance in order to provide disinfection with a minimum amount of chlorine. Marske and Boyle (2) demonstrated by tracer studies of chlorine contact tanks that adequate plug flow hydraulics were practically achievable with length-to-width (L/W) ratios of 40:1 to 70:1. Another field study (16) revealed that a dispersion number of 0.015 has been achieved by L/W ratios ranging from 30:1 to 70:1. (The dispersion number is a measure of plug flow.) However, there has never been an agreement on which criterion is adequate. It should be noted that the length L used herein is the total length of the flow path in a baffled tank, and W is the width of that flow path.

The distribution of residence times provided by the contact tanks was determined at each location by using dye tracer techniques and a recording fluorometer. The tracer curve provides a convenient method of evaluating the overall hydraulic performance of the tanks. It indicates the actual contact time and the dispersion characteristics. The smaller the dispersion, the more closely a tank approaches plug flow characteristics. The most important dispersion characteristics are:

$T = V/Q$ = theoretical detention time;

t_1 = minimum contact time; i.e., the first appearance of tracer in the effluent;

t_m = modal time; i.e., time to the peak of the curve;

t_a = average contact time; i.e., time to the centroid of the curve;

d = dispersion number, computed from the variance of the tracer curve (5,15,16).

The dispersion number varies from infinity for completely mixed flow to zero for ideal plug flow. Trussell and Chao (17) believe, on the basis of theoretical considerations, that a dispersion number of 0.01 is adequate for chlorine contact tanks.

In addition to plug flow, the provision of adequate minimum contact time, t_1 , is also important to prevent short-circuiting of inadequately disinfected effluent. The California Department of Health Services has recommended a t_1 of 30 minutes at maximum flow (23).

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Chlorine Residual - Contact Time Relationships. - The optimized pilot plant was equipped with sampling taps which enabled sampling after chlorine contact times ranging from 15 minutes to two hours. In addition, during one study week, the chlorine residual on the pilot plant was varied at each location. This provided means for determining the relative effects of chlorine residual and contact time on disinfection efficiency, as well as the effectiveness of the system in meeting bacteriological requirements with minimum amount of chlorine.

The following empirical formula, developed by Collins and Selleck (14) in a pilot plant study, was used to evaluate disinfection efficiency:

$$N_1/N_0 = (R - T/b)^n \quad (1)$$

Where N_1 = bacterial density in chlorinated effluent at time T ;

N_0 = bacterial density in unchlorinated effluent;

R = chlorine residual, mg/l, after contact;

T = contact time, minutes;

n = slope of the curve;

b = the X- intercept when $N_1/N_0 = 1.0$, mg/l x minutes.

This formula plots as a straight line on double-log paper with a slope of n and an intercept b at $N_1/N_0 = 1.0$. Collins and Selleck (14) found that the slope was -3 for plug flow and -1.5 for completely mixed flow. The ratio N_1/N_0 is the bacterial survival ratio. In this current study it wasn't possible to measure chlorine residual immediately after mixing at all the treatment plants; therefore, the chlorine residual after contact, R , was used for comparative studies. In order to enable direct comparison of pilot plant and full-scale system results, the theoretical detention time, T , was used in all calculations.

Initial Mixing. - It has long been known that inadequate initial mixing of the chlorine and wastewater can result in poor disinfection efficiency (11). Attempts to compensate for poor initial mixing by increasing the chlorine dosage may do little to improve disinfection but may add an appreciable amount of toxic residual to the effluent. Heukelekian and Day (12) demonstrated conclusively in 1951 that the distribution of chlorine residual in plant contact tanks will not be uniform unless special mixing compartments are provided. Without special mixing, the greater portion of the chlorine passes along the bottom of the tanks resulting in poor overall bacterial removals in spite of a significant chlorine residual in the effluent. Unfortunately, it has been common practice for the chlorine solution to be applied directly to chlorine contact tanks or to open channels, often without a diffuser. Flows in those contact tanks and in many open channels may be highly stratified resulting in very little dispersion of the chlorine. The net result of poor initial mixing is reduced disinfection efficiency, and excessive use of chlorine.

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In addition, this study has shown that a high degree of coliform destruction occurs during initial mixing. This also helps to improve the overall disinfection efficiency of a system.

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The efficiency of mixing was determined at selected plants by measuring chlorine residual and total coliform bacteria before and after mixing. An assessment was also made of the energy input to the mixing system, where possible, to obtain useful design information. The mixing study on the pilot plant was done concurrently with the degree of disinfection study.

Effluent Quality. - The wastewater effluent from each plant was analyzed during each study period for major chemical components in order to determine the effects of wastewater characteristics on disinfection efficiency.

Little is known about the specific effects of wastewater quality on the disinfection process. It is generally understood that the quality of the wastewater may affect disinfection efficiency when the ammonia and organic nitrogen contents are sufficiently low so that free chlorine is present. Appreciable changes in temperature and pH will affect the bacterial reduction rate, and constituents such as particulate matter may interfere with disinfection, especially during the latter stages of the disinfection process. Collins (13) reported no appreciable differences in the disinfection rates observed in a chlorinated primary effluent and in a chlorinated activated sludge effluent during the first several orders of magnitude of bacterial kill. It appears that the effects of initial mixing and the distribution of residence times overshadow the effects of wastewater quality during the early stages of the disinfection process; however, in order to achieve consistently low coliform concentrations after disinfection, the effect of effluent quality constituents must be considered. Consequently, if strict bacteriological standards are to be met consistently, additional treatment may be needed to remove interfering constituents. The few plants in California that consistently achieve the stricter State coliform standards either employ filtration ahead of disinfection or excessively high chlorine residuals.

Degree of Disinfection. - The wastewater treatment plants which were selected for study provided different types and degrees of treatment. During one of the four study weeks at each site, the pilot plant's chlorine residual was varied to achieve total coliform levels ranging from 2 per 100 ml to 1000 per 100 ml when possible. This enabled an evaluation of the chlorine dose and residual required in various effluents to achieve several levels of disinfection.

Comparative Multiple Tube and Membrane Filter Study. - Two techniques are available for the enumeration of coliform bacteria — the multiple tube technique and the membrane filter (MF) method. The MF procedure has been well received; however, there have been some reservations as to reproducibility of results on chlorinated effluents (24).

For the field studies, coliform bacteria were routinely analyzed by the multiple-tube fermentation technique using five tubes for each dilution. In order to provide a significant body of information on the comparative use of the MF method, every fifth sample of chlorinated effluent collected from each treatment plant was also analyzed by the MF procedure.

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Dechlorination. - Elimination of chlorine-induced toxicity by the use of sulfur dioxide was evaluated by means of 96-hour continuous-flow bioassays at selected plants.

Process Control and Instrumentation. - Optimum disinfection requires accurate and rapid regulation of the chlorine dosage in response to the concentration of the chlorine residual and this can be achieved only by automatic chlorine residual control. The plants studied had various methods of controlling chlorine feed rate, such as manual, flow proportional and residual control. The effectiveness of the various control systems used was evaluated and related to that of the optimized pilot plant which had well adjusted automatic chlorine residual control. The flow through the pilot plant was constant, eliminating the need for flow-proportional control.

Toxicity Measurements. - The toxicity of the effluents was determined by the DFG by means of 96-hour, continual-flow fish bioassays.

Three bioassays were conducted simultaneously at each plant studied for at least two runs, on the following effluents: a) existing treatment plant chlorinated effluent, b) effluent immediately prior to chlorination, and c) effluent from the optimized pilot plant. The chlorine residual was reduced in the optimized plant effluent to the minimum amount required to meet the same total coliform level after the same contact time as the full-scale plant.

The fathead minnow (*Pimephales promelas*) and the golden shiner (*Notemigonus crysoleucas*) were used as the test species. Activated carbon treated tap water was used for dilution water. Dissolved oxygen and temperature were artificially maintained at levels adequate to sustain fish. Chlorine residuals in each waste stream were measured every two hours throughout the clock. The details of this study are discussed in Volume II of this report (21).

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SECTION 3

MATERIALS AND METHODS

OPTIMIZED CHLORINATION PILOT PLANT

A trailer mounted mobile chlorination pilot plant was designed by project staff and constructed by a private contractor. Although the pilot plant wasn't optimized in a mathematical sense, it incorporated the following optimum design criteria: a) rapid initial mixing, b) automatic direct residual control of chlorine dosage, and c) plug flow type chlorine contact tanks providing up to two hours detention. The various elements of the optimum design criteria are further discussed in the design manual. (23)

Figure 1 shows the basic elements of the chlorine control system. During normal operation, a constant effluent flow of 1.9 l/s (30 gpm) is conveyed to the pilot plant by means of a variable speed positive displacement pump. Chlorine is injected under pressure through a 38 mm (1.5-inch) tee which provides instantaneous mixing of chlorine solution with the process stream. The mixer is removable and can be replaced by a 76 mm (3-inch) tee. At a point of 10-pipe diameters downstream from the tee a quantity of chlorinated effluent is taken by the booster pump and 0.6 l/s (10 gpm) of this flow is conveyed to the chlorine residual analyzer. The remainder is used to operate the injector in the chlorinator. The analyzer automatically controls the chlorine dosage in response to chlorine residual at the control point by means of variable vacuum signal. The analyzer also records the residual on a chart. The loop time is very short, approximately 1.5 minutes.

A flow of 0.6 l/s (10 gpm) is wasted deliberately because the 1.9 l/s (30 gpm) intake is necessary to provide a practical working range for the chlorinator. This leaves a 1.2 l/s (20 gpm) flow for the pilot plant (see Figure 1). All flows are metered by appropriate rotameters. All materials in contact with flow stream are either PVC plastic or stainless steel to prevent toxicity to test fish. In order to assure instrument compatibility, the entire control system is made by the same manufacturer.

The 0.6 l/s (10 gpm) flow is metered and conveyed to the chlorine contact tanks. The flow schematic of the tanks is shown on Figure 2. The rectangular tanks are divided by baffles into eight cells; each cell is 200 mm (8 inches) wide and 400 mm (16 inches) deep and provides 15 minutes detention. With all cells in series the total detention time is 120 minutes. Sampling taps are provided at every 15 minute interval.

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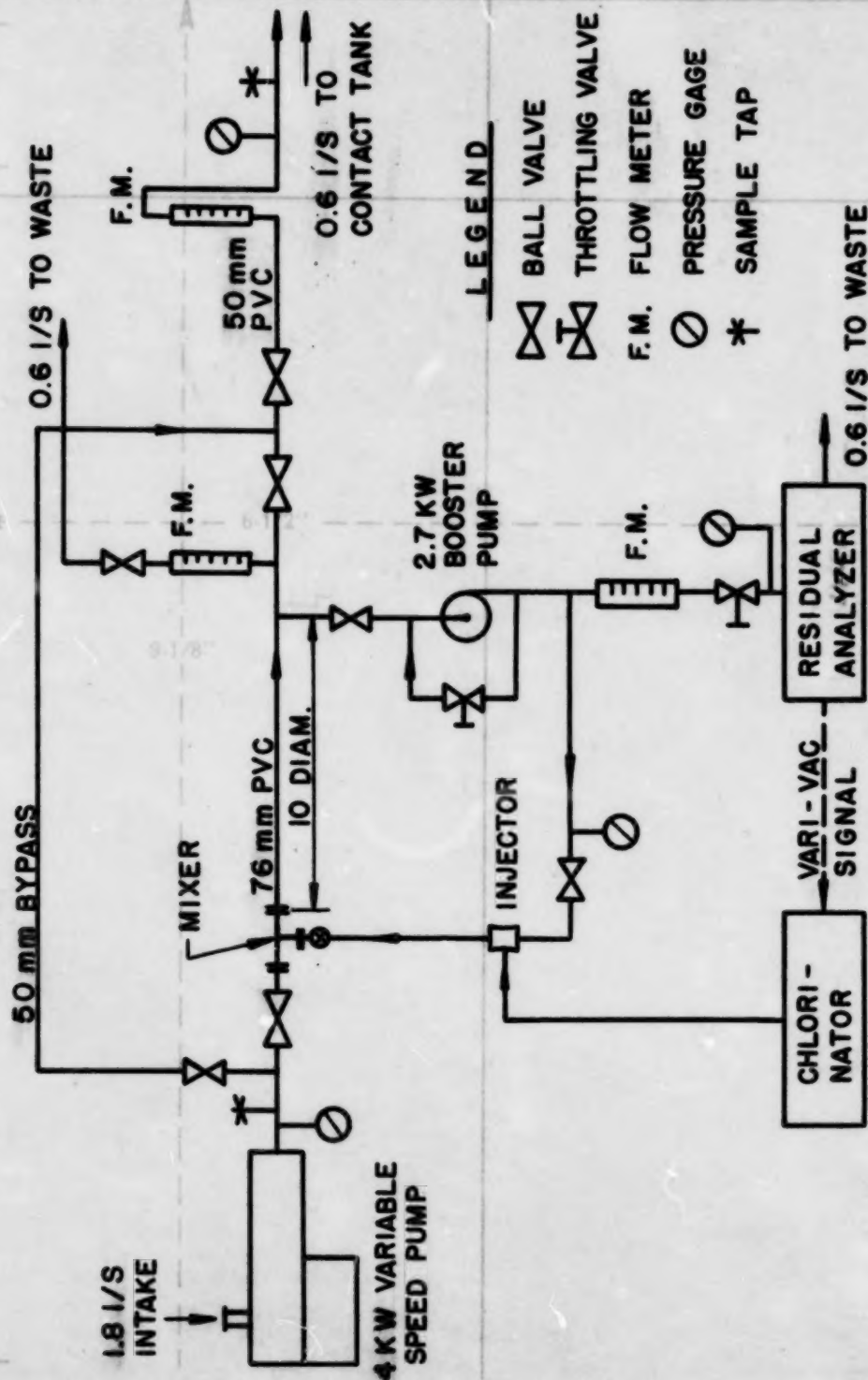


Figure 1. Pilot Plant Chlorine Control System.

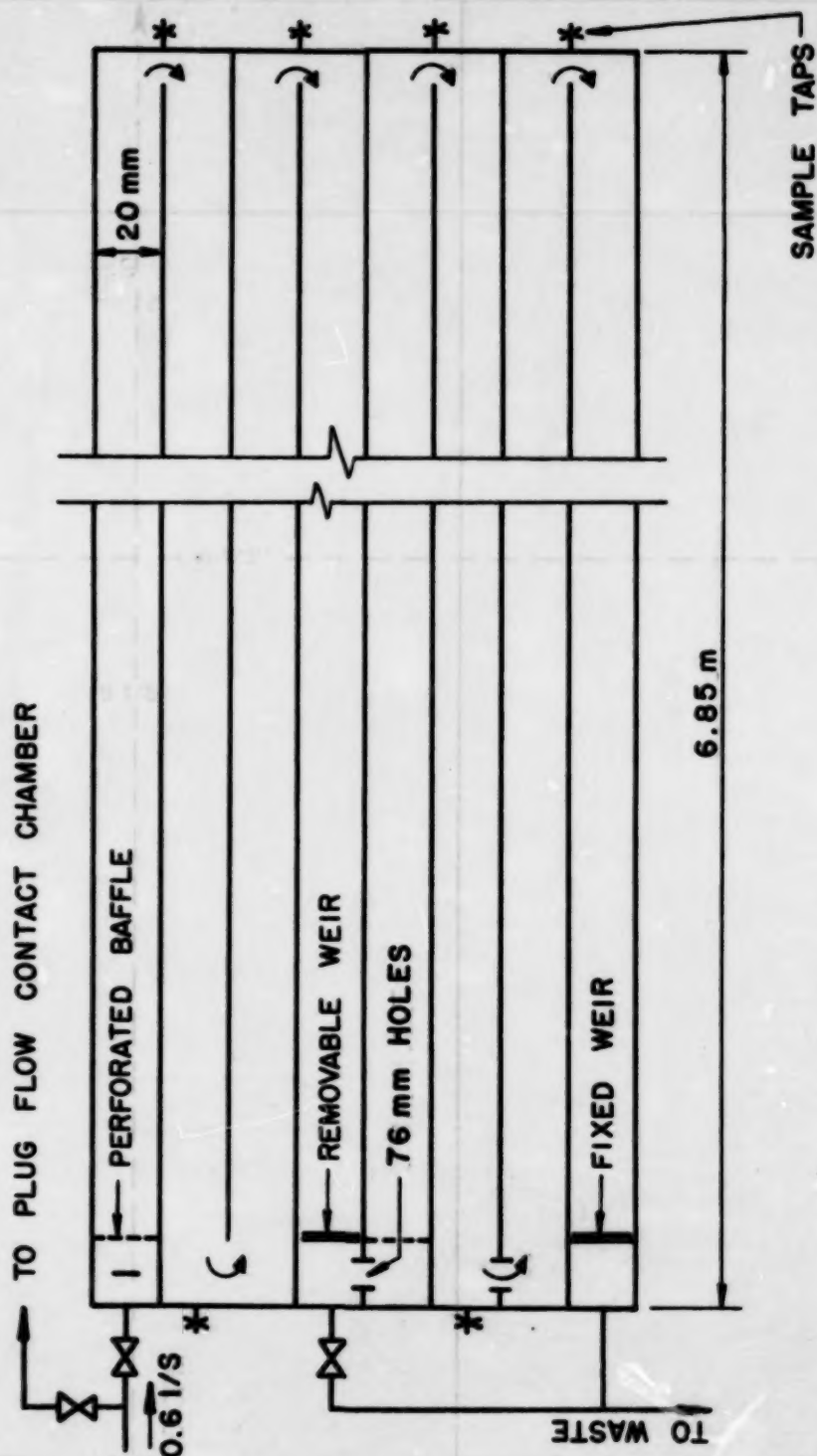


Figure 2. Pilot Plant Chlorine Contact Tanks.

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The contact tank is separated into two equal sections by means of small openings in the dividing wall. Section I can be operated independently by closing these openings, installing a weir and opening a valve to waste. Inlets are provided with perforated plate cross baffles to distribute the flow. The tanks are coated with epoxy paint to provide corrosion resistance.

In addition to the rectangular baffled tank, there is a plug flow contact chamber consisting of 280m (920 feet) of 5cm (2-inch) PVC pipe which provides 15 minutes detention time at design flow.

Table 1. PILOT PLANT TRACER STUDY RESULTS

Parameter	Section I	Sections I & II in Series
Theoretical Detention, T	60 min.	120 min.
t_i/T	0.63	0.71
t_m/T	0.82	0.92
t_a/T	0.94	1.03
Dispersion Number, d	0.023	0.021
Length-to-Width Ratio, L/W	135	270

Table 1 and Figure 3 show the results of tracer studies done on the rectangular tanks. The results show that the tanks deviate considerably from ideal plug flow, and that despite the increasing length-to-width ratio the dispersion number "d" does not decrease noticeably. This is apparently due to the drag on the sides of the deep and narrow tank, density currents, and some dead space which cause the long tail of the tracer curve. The other dispersion characteristics, however, increase with series operation.

FIELD AND LABORATORY ANALYSES

Samples for coliform bacteria analysis were taken four times per day at selected sampling stations between the hours of 8:00 A.M. and 3:00 P.M. Samples were dechlorinated immediately and analyzed in the mobile public health laboratory located on the plant site. Each sampling included determination of plant flow, chlorine feed rate, temperature, pH, and chlorine residual. Daily 8-hour composite samples were taken of unchlorinated effluent and analyzed for total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total

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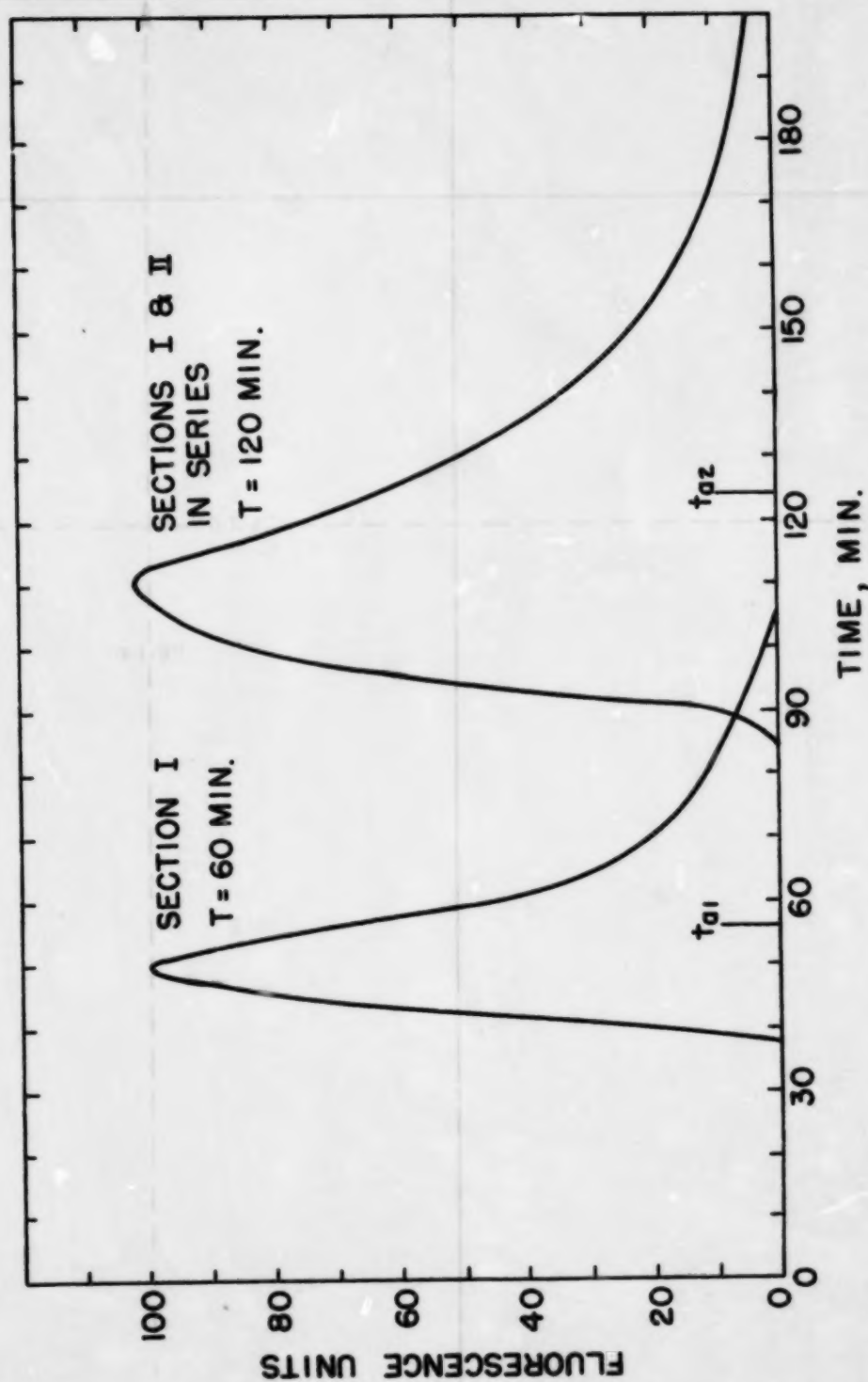


Figure 3. Pilot Plant Residence Time Distribution.

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and volatile suspended solids (TSS, VSS), alkalinity, electrical conductivity, nitrite-nitrogen, nitrate-nitrogen, organic-nitrogen and ammonia-nitrogen. Most of these analyses were done in the Sanitation and Radiation Laboratory in Berkeley.

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Except as indicated otherwise, all analyses were done according to "Standard Methods" (18). Total coliform bacteria were analyzed by the confirmed test multiple tube (MT) method using five tubes per dilution and two replicates per sample. In addition, every fifth chlorinated sample was also analyzed by the standard membrane filter (MF) procedure, including the enrichment step (18). The pH was determined by a portable pH meter. Chlorine residual for the DHS studies was determined by the indirect (back titration) iodometric procedure using starch for the end point (18).

Nitrite was determined by the EPA method (19). Nitrate was determined by the brucine method (18).

Tracer studies on chlorine contact tanks were done by using Rhodamine WT dye as the tracer and a Turner recording fluorometer for measuring fluorescence.

Chemical analyses used for the DFG toxicity studies are discussed in Volume II of this report (21).

TREATMENT PLANTS STUDIED

The treatment plants studied all had at least secondary treatment; however, the waste characteristics and the treatment methods differed. The chlorination systems contained a variety of different types of mixers, chlorine control systems and contact tanks. Table 2 lists the different facilities at the treatment plants studied. The following is a description of each plant presented in the order of which the studies were done.

San Leandro

The San Leandro plant consists of primary and secondary sedimentation, completely mixed activated sludge, followed by chlorination and 2.8 ha (7 acres) of aerated ponds. There is also a trickling filter which was not in use during the study. The design flow is 30,000 m³/d (8 mgd). (The actual flow was considerably higher than that). The City has 6 major industries, and the incoming wastewater contains about 40-50% by flow industrial wastes, including food, milk and paper wastes. The disinfection system consists of a 2700 kg/d (6000 lb/d) Fisher and Porter (F&P) chlorinator and a spirovortex contact tank which provides about 45 minutes theoretical detention. Chlorine is added through a 100 mm (4") diffuser into a 0.9 m (36") pipe approximately 30 m (100 feet) before it enters the contact tank. This pipe, which is under pressure, functions as the mixer. Chlorine dosage is controlled manually, based on influent flow and chlorine residual tests. The aerated ponds which follow the chlorination system provide final treatment and also function as the dechlorination system. The ponds provide about 2 days detention. The effluent presently flows directly into the San Francisco Bay, but will soon be connected to a regional outfall.

During the study unchlorinated effluent was taken from the secondary clarifiers, prior to pond treatment. During the study period the plant experienced severe overflows of sludge and grease. In addition, there was heavy rainfall which caused

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Table 2. TREATMENT PLANT DATA

Treatment Plant	Disinfection Standards Total Coliform MPN/100 ml	Waste Characteristic	Treatment ^a	Chlorine Control	Mixer	Chlorine Contact
San Leandro	240	Domestic & Industrial	A.S.	Manual	Pipe	Spirovortex
San Pablo	240	Domestic & Industrial	A.S. Nitrification	Compound Loop	Hydraulic jump	Rectangular, once-around
Pinole	240	Domestic	A.S.	Compound loop	Turbine	Serpentine
South San Francisco	240 ^b	Domestic & Industrial	A.S.	Compound loop	Pipe	Spirovortex
Sacramento Co. Sanitation District, Northeast Roseville	100	Domestic	A.S.	Compound loop	Turbine	Circular plus serpentine
	23	Domestic	A.S. plus Filter	Compound loop	Turbine	Serpentine
Dublin-San Ramon	2	Domestic	A.S. Nitrification plus Filter	Compound loop	Turbine	Rectangular, once-around
Ross Valley	240	Domestic	Trickling Filter	Flow Prop.	Hydraulic jump	Rectangular, once-around

^a Note: A.S. means activated sludge.

^b Not in force during the study.

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flooding. Consequently, the pilot plant clogged up quickly and could be operated only for three hours in the morning before the peak flow was reached.

West Contra Costa Sanitary District (San Pablo)

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The San Pablo treatment plant consists of primary and secondary sedimentation, roughing trickling filtration, activated sludge, nitrification, pH control, and chlorine disinfection. The incoming wastewater contains about 25-30% industrial waste, including trucking and chemical wastes. The design flow is 47,000 m³/d (12.5 mgd). The disinfection system consists of two 900 kg/d (2000 lbs/d) Wallace & Tiernan (W&T) chlorinators, rapid mixing, two parallel baffled contact tanks with an L/W of 15:1 and sulfur dioxide (SO₂) dechlorination. Chlorine is added by 76 mm (3") diffuser into the exit from the final clarifier. At this point there is a fall of about 1.8 m into a 1.4 m (54") pipe. This device acts as the mixer simulating a hydraulic jump. Chlorine is controlled by an effluent flow pacing signal and a signal from the Fisher and Porter (F&P) residual analyzer which gets its sample from the entrance to the contact tank. The two parallel tanks provide about 75 minutes theoretical detention. Due to complete nitrification the pH is depressed to about 6.0-6.5. After the chlorine contact, both caustic and SO₂ are added to two separate effluent streams. The SO₂ is added into each Parshall flume, and its dose is controlled by effluent flow pacing and 2 additional residual analyzers. The two streams combine into a lined ditch which conveys the disinfected, dechlorinated effluent to the San Pablo Bay.

Effluent for study was taken from the final clarifier prior to chlorination.

Pinole

The Pinole treatment plant consists of primary and secondary sedimentation, conventional activated sludge, and chlorine disinfection. The wastewater is almost entirely domestic, with small amounts of industrial wastes including methanol and urea. The design flow of the plant is 7600 m³/d (2 mgd). The disinfection system consists of a W&T chlorinator, two 2 kW (1.5 HP) turbine mixers, two parallel serpentine contact tanks, and SO₂ dechlorination. Chlorine is injected through the same diffuser into each mixing chamber below the turbine impellers. Chlorine control is by effluent flow pacing and a W&T residual analyzer which gets its sample from the contact tank directly after initial mixing. The contact tanks have corrugated fiberglass baffles which provide a L/W ratio of 40:1, and in addition, have turning vanes at each 180° turn. Due to baffle leakage, and short contact time, however, the performance of the tanks has been poor (See Section 4). Although the mean detention time was about 45 minutes, the t_c was on the order of 15 minutes. SO₂ is added by diffusers into the channel at the end of the contact tanks. The SO₂ feed rate is controlled by effluent flow pacing and a second residual analyzer. The dechlorinated effluent flows through an outfall into San Pablo Bay. It is planned to connect the effluent to a regional outfall in the future.

During the study secondary effluent was taken from a diversion box prior to chlorination. The plant experienced rapid quality changes, partial nitrification, and a very high chlorine demand.

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South San Francisco - San Bruno

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The South San Francisco - San Bruno treatment plant consists of primary and secondary sedimentation, conventional activated sludge, and chlorination. The design flow is 49,000 m³/d (13 mgd). Industrial wastes comprise 30% of the flow and consist of dairy, food processing, plating and chemical wastes. The chlorination system consists of a W&T chlorinator, compound loop chlorine control system, and a spirovortex contact tank. Chlorine is injected through a diffuser into a 1.4 m (54-inch) pipe 15m (50 feet) ahead of the contact tank. Since the distance from the injection point to the analyzer sampling point is very short the mixing is poor. The control analyzer exhibits periodic fluctuations between zero and 10 mg/l residual. The contact tank provides about 30 minutes theoretical detention; however, the minimum contact time, t_c , is only 7 minutes. Effluent is pumped to a joint outfall where it is dechlorinated with SO₂ prior to discharge to San Francisco Bay.

During the study the plant was under no constraint to meet an effluent bacteriological standard, and, therefore, plant personnel did not strive to provide adequate disinfection. Unchlorinated effluent was taken from one of the final clarifiers. During the study the sludge disposal mechanism was out of order and all waste activated sludge was dumped into the final clarifiers. This resulted in massive sludge overflows during maximum flow periods, usually at noontime and sometimes also at midnight. Each time the pilot plant analyzer clogged up and had to be cleaned and recalibrated. The pilot plant's contact tanks filled up to over 1/3 depth with sludge at the end of a 4-day run.

Sacramento County Sanitary District - Northeast

The Northeast treatment plant consists of prechlorination, primary and secondary sedimentation, both conventional and Walker Process activated sludge, and chlorine disinfection. The wastewater is entirely domestic, and the design flow is 80,000 m³/d (21 mgd). Effluent quality is good, and the plant disinfects to an MPN level of 2 per 100 ml. The disinfection system consists of a 2700 kg/d (6000 lbs/d) W&T chlorinator, 13.3 kW (10 HP) turbine mixer, residual analyzer, circular and rectangular serpentine chlorine contact tanks and SO₂ dechlorination. Chlorine is injected through a diffuser located below the mixer turbine. The chlorinated effluent then flows first through two parallel circular tanks and subsequently into a serpentine baffled tank which has an L/W ratio of 100. The three tanks provide a total of 85 minutes theoretical detention; however, dye studies show that the circular tanks have a very short t_c (See Section 4). Chlorine is controlled by a flow signal from the influent meter¹ and by a chlorine residual signal derived from the mixing chamber. Dechlorination is by sulfur dioxide which is controlled by the feed forward mode. The SO₂ is added by a diffuser into the flow coming over the effluent weir of the contact tank. There is a 2.4 m (8-foot) fall below this weir which provides adequate mixing. Dechlorinated effluent is conveyed by an outfall into the American River.

During the study unchlorinated effluent was taken from a pump well located 3 m (10 feet) upstream from the turbine mixer. During low flows at night there was some backmixing from the turbine into the pump well resulting in the occasional presence of chlorine residual in the pump well during that period. However, there was no backmixing during normal flows. There was a considerable amount of filamentous algae in the effluent due to cleaning of the final clarifiers by the operators.

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Roseville

The Roseville treatment plant consists of primary and secondary sedimentation, completely mixed activated sludge, dual media filtration, chlorination and dechlorination. The wastewater is entirely domestic and the design flow is 20,000 m³/d (5.2 mgd). There is also a large storage pond which is used for effluent overflow purposes. The plant has many modern control instruments which do not function properly. The chlorination system consists of a 450 kg/d (1000 lb/d) W&T chlorinator, compound loop chlorine control system, a 4 kW (3 HP) turbine mixer, and a plug flow type baffled contact tank. Chlorine is injected into a pipe ahead of the mixer. Chlorine control is paced by the effluent flow meter which is subject to large fluctuations in flow during the filter backwash cycle. This condition lasts for several hours, and has the effect of causing large fluctuations in chlorine dosage as well as the control residual. The chlorine contact tank has a length-to-width ratio of 60 and provides 90-120 minutes theoretical detention. Dye studies indicate that the tank has good plug flow characteristics. The effluent is dechlorinated with SO₂ before discharging into Dry Creek. The SO₂ is controlled by the feed forward mode. The effluent is disinfected to a total coliform level of 2 per 100 ml prior to discharge.

During the study unchlorinated effluent was taken from the storage tank located on top of one of the filters. During the first and second week some of the pond effluent was redirected through the plant which caused green discoloration and suspended solids in the filtered effluent. During the weekend following the first week there was a sludge bulking problem and the filters clogged up. Shortly thereafter, heavy rains started, and the filters were bypassed for most of the second week. No work could be done during that period. Throughout the study the treatment plant experienced alkalinity stripping, and during the last week partial nitrification.

Dublin - San Ramon Services District

The Dublin-San Ramon treatment plant has a design capacity of 15,000 m³/d (4.0 mgd) and receives only domestic wastes. Treatment consists of primary and secondary clarification, flow equalization, activated sludge, nitrification, mixed media filtration, pH adjustment, chlorination and SO₂ dechlorination. The chlorination system consists of a 900 kg/d (2000 lb/d) F&P chlorinator, a compound loop control system with a Delta Scientific analyzer, 13 kW (10 HP) turbine mixer, and a rectangular baffled contact tank. Chlorine is injected through a diffuser located below the mixer turbine.

The contact tank nominally provides 60 minutes theoretical detention. A portion of chlorinated effluent is pumped into the plant reclaimed water system. Filter backwash water is taken from the end of the contact tank. Sulfur dioxide is added by means of a diffuser located at the effluent weir of the contact tank, and the SO₂ dose is controlled by effluent flow pacing and a second analyzer. During filter backwash, which takes about three hours, there is a great fluctuation of effluent flow and the water level in the contact tank is drawn down. This fluctuation adversely affects the chlorine feed rate.

The treatment plant disinfects to a total coliform MPN level of 2 per 100 ml. Effluent is discharged to a tributary of the Niles Creek. Unchlorinated effluent for the study was taken from the pipe conveying filtered effluent to the chlorine

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mixer. The intake was located at an adequate distance upstream to assure no backmixing of chlorine.

Ross Valley Sanitary District

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The Ross Valley treatment plant is designed for 19,000 m³/d (5.0 mgd) and treats only domestic wastes. Present flows are higher than design flows. Treatment consists of primary and secondary sedimentation, 3-stage trickling filtration, micro-screening, chlorination and SO₂ dechlorination. The chlorination system consists of 900 kg/d (2000 lb/d) W&T chlorinator and a baffled contact tank of trapezoidal cross section. The tank provides less than 30 minutes theoretical detention. Chlorine dose is controlled by a flow signal derived from the effluent flow meter. However, due to influent pumping the flow varies frequently from 11,000 m³/d (3 mgd) to 33,000 m³/d (9 mgd) which adversely affects the chlorine feed rate.

A residual analyzer is available for SO₂ control but does not function properly. Chlorine is injected at the weir of the secondary clarifier. At this point there is a 1.2 m (4-foot) drop which acts as a hydraulic jump and provides initial mixing. Sulfur dioxide, controlled by flow pacing, is injected into the outfall pipe. Dechlorinated effluent is discharged into San Francisco Bay.

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SECTION 4

RESULTS AND DISCUSSION

GENERAL

During the first week at each location the pilot plant effluent was adjusted as closely as possible to the same total coliform level, after the same detention time, as the full-scale plant. This was quite difficult because the MPN of the full-scale effluent was not known beforehand and the bacteriological results only became available four days later; by then the water quality had already changed. Presumptive MPN enumerations were useful at some but not every location. Moreover, the treatment plants usually over-chlorinated which resulted in a much lower total coliform level than those stipulated in effluent standards. The water quality, including the initial total coliform level, varied from day-to-day and week-to-week. In most cases, it was possible to achieve a fairly consistent level of disinfection in the pilot plant by maintaining a constant chlorine residual. This, however, required considerable effort because the residual analyzer had a tendency to clog and lose calibration.

Plant flow meter readings were used to calculate the chlorine dosages and contact times. Therefore, the accuracy of these determinations is dependent on the accuracy of the existing flow meters.

COMPARATIVE STUDY -- PILOT PLANT VERSUS FULL-SCALE PLANTS

Two weeks at each site were devoted to the comparative study of testing the performance of the pilot system against that of the full-scale system. Table 3 summarizes the results of concurrent studies done on the pilot plant and the full-scale plant. The table shows the chlorine dose and residual used to achieve approximately the same total coliform level after the same contact time. The basic data are presented in the Appendix. Similar results were obtained in the pilot plant as compared to the full-scale plant with significantly lower chlorine dosage at all the test sites except one. Table 4 shows the calculated mean chlorine dosages used by the pilot system and the full-scale system at the 6 locations where adequate data were obtained. The percent chlorine dosage reduction achieved in the pilot system ranged from 18.6 percent at San Pablo to 56.1 percent at Pinole. The results at San Leandro remain undetermined for reasons explained below. The South San Francisco plant did not apply enough chlorine to achieve adequate disinfection or a consistent effluent MPN. Therefore, it wasn't possible to properly adjust the pilot plant at that site and the results shown are not comparable. Overall, the pilot plant used 46.7 percent less chlorine than the full-scale plants, which amounts to an average savings in chlorine of 7.8 mg/l.

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Table 3. RESULTS OF COMPARATIVE CHLORINATION STUDIES^a

Treatment Plant	Coliform Level, MPN/100 ml	Contact Time, Minutes	Chlorine Dosage, mg/l	Chlorine Residual, mg/l ^b
San Leandro Plant ^c	2 - 11	47 - 56	12.0 - 13.0 ^c	7.8 - 10.7
Pilot Plant at San Leandro	22 - 132	45	11.0 - 13.0	6.0 - 6.5
San Pablo Plant	13 - 64	70 - 78	9.2 - 10.6	1.2 - 2.5
Pilot Plant at San Pablo	7 - 20	60	7.9 - 8.8	1.5 - 2.4
Pinole Plant	2 - 640	45 - 52	27.9 - 47.2	5.5 - 13.6
Pilot Plant at Pinole	< 2 - 200	45	7.5 - 27.7	2.5 - 3.7
So. San Francisco Plant ^d	2800-26,150	24 - 32	5.3 - 10.2	0.9 - 4.4
Pilot Plant at So. S.F.	20 - 280	30	9.2 - 11.2	2.9 - 4.2
Sacramento N.E. Plant	< 2 - 2	79 - 86	9.0 - 13.3	6.7 - 9.1
Pilot Plant at Sacramento	< 2 - 2	90	3.7 - 7.0	1.4 - 3.6
Roseville Plant	< 2 - 2	89 - 110	7.9 - 16.7	3.8 - 5.4
Pilot Plant at Roseville	< 2 - 33	90	4.0 - 6.9	1.6 - 2.6
Dublin-San Ramon Plant	< 2 - 5	43 - 64	14.2 - 20.7	7.2 - 13.0
Pilot Plant at Dublin	< 2 - 10	60	10.6 - 12.4	3.8 - 6.8
Ross Valley Plant	13 - 230	22 - 35	6.5 - 20.2	5.1 - 7.9
Pilot Plant at Ross Valley	8 - 17	30	6.3 - 7.2	2.9 - 3.6

^a Daily median values.

^b Chlorine residual after indicated contact time.

^c Erroneous dosage estimate; one week's results shown.

^d No adequate disinfection practiced; one week's results shown.

**Table 4. MEAN CHLORINE DOSAGE USED BY
THE OPTIMIZED PILOT PLANT
AND
FULL-SCALE PLANT IN COMPARATIVE STUDIES^a**

Location	Chlorine Dosage, mg/l ^b		Percent Reduction in Pilot Plant
	Full-scale Plant	Pilot Plant	
San Pablo	10.2 ± 0.89	8.3 ± 0.38	18.6
Pinole	37.4 ± 9.86	16.4 ± 8.13	56.1
Sacramento	10.5 ± 1.98	5.8 ± 1.27	44.8
Roseville	10.6 ± 3.20	4.7 ± 0.86	55.7
Dublin-San Ramon	16.7 ± 3.73	11.6 ± 1.09	30.5
Ross Valley	14.8 ± 8.5	6.7 ± 0.38	54.8
Overall Mean	16.7 ± 10.5	8.9 ± 4.4	46.7%

^a During daytime sampling period.

^b Arithmetic mean ± standard deviation.

Some of the individual results shown above are perplexing and require an explanation. The San Leandro results shown in Table 3 are misleading. As judged by the optimum design criteria, this plant had the worst design and, therefore the relative chlorine dosage reduction should have been the greatest. From Table 3 it can be seen that the measured pilot plant's chlorine residual was about 30 percent lower than that of the full-scale plant. Table 8 shows that this effluent had a very high chlorine demand. It is evident that the chlorine dosages at this plant were underestimated, for the following reasons: 1) Due to fogging of the rotameter it was often not possible to read the chlorine feed rate. In this case the plant management's estimates were used; these were always the same and apparently wrong. 2) The plant flow was overestimated. Due to the constant on and off action of the influent pumps it was not possible to accurately read the flow rate. Moreover, the measured flow was influent flow, and there was a lag time of several hours to the chlorine contact tank. If the flow rates were overestimated, then the calculated contact times were underestimated.

Furthermore, the samples at San Leandro full-scale plant were taken from a long sampling hose used to convey effluent to the DFG bioassay laboratory, which added approximately 10 minutes of plug flow contact time to the samples. This hose was used for sampling because at that time the DHS did not yet have the necessary sampling equipment. Consequently, the total t_c (contact tank plus hose) at the sampling point was on the order of 15-20 minutes. This may explain the low MPN's in that effluent. Due to the constant sludge and grease carryover problem, it was possible to operate the pilot plant only three hours per day; therefore, the pilot plant data are incomplete.

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At San Pablo the pilot plant results would have been better if the pilot system had been properly adjusted. From Table 3 it can be seen that the pilot plant effluent had a lower MPN than the full-scale system despite a considerably shorter contact time. Therefore, it appears that the pilot plant was run at a too high chlorine residual. The difficulty in adjusting the pilot plant to the "correct" MPN has already been pointed out. Moreover, at this site, the pilot chlorine control mechanism exhibited large periodic fluctuations which made proper adjustment difficult. The study was nearly over before the mechanism could be adjusted.

The Roseville plant appeared to have the best design of the eight plants; therefore, the difference in the results should have been the least. The only obvious deficiency at that plant was poor chlorine control during the filter backwash. However, from Table A-6 in the Appendix, it appears that this plant was overchlorinating in order to meet the MPN of 2 per 100 ml standard.

The better results obtained in the pilot system apparently were due to certain design and operational deficiencies in the existing plants. As seen from Table 10, all the full-scale plants except San Pablo had poorly designed and/or operated chlorine control systems. All plants except Roseville and Dublin-San Ramon had poor chlorine contact systems (poor plug flow or short contact times). The evaluation of the contact tanks, chlorine controls, and mixers are discussed in subsequent Sections. Whether the pilot plant's mixer was better than the full-scale mixers remains undetermined.

The comparative study results are further discussed under the heading Chlorine Residual — Contact Time Relationships.

RESIDENCE TIME DISTRIBUTION IN CONTACT TANKS

The residence time distribution curves of each chlorine contact tank studied, together with a flow schematic of each tank, are depicted on Figures 4 to 12. These curves were derived from dye tracer studies conducted during daily peak flow periods. Each dye test was done by injecting a slug of dye instantaneously into the tank inlet, the mixer, or some other accessible point upstream, and measuring the fluorescence in the tank effluent. The calculated dispersion data are shown in Table 5. When comparing the data in the table, it is apparent that the pilot tank provided better plug flow hydraulics than most of the full-scale tanks. The calculated t_d of the pilot tank was also longer than the t_d of 6 of the full-scale tanks in the comparative studies. However, three of the baffled tanks had a smaller dispersion number than the pilot tank, although one of them (Ross Valley) had a very short t_d (15 minutes at peak flow, see Figure 12). This shows that the use of the dispersion number alone is not sufficient for the evaluation of a tank, and that t_d value and the extent of dead space must also be considered. The dispersion number does not measure dead space. These three plants also exhibited a poor overall performance relative to that of the pilot plant (Tables 3 and 4), which indicates that the achievement of perfect plug flow may not be as important as was believed to be.

The DHS has recommended a t_d of 30 minutes at peak flow, based on observation of various plants (23). Plants with much smaller contact times have experienced difficulties in meeting effluent standards or have used excessive chlorine dosages and residuals.

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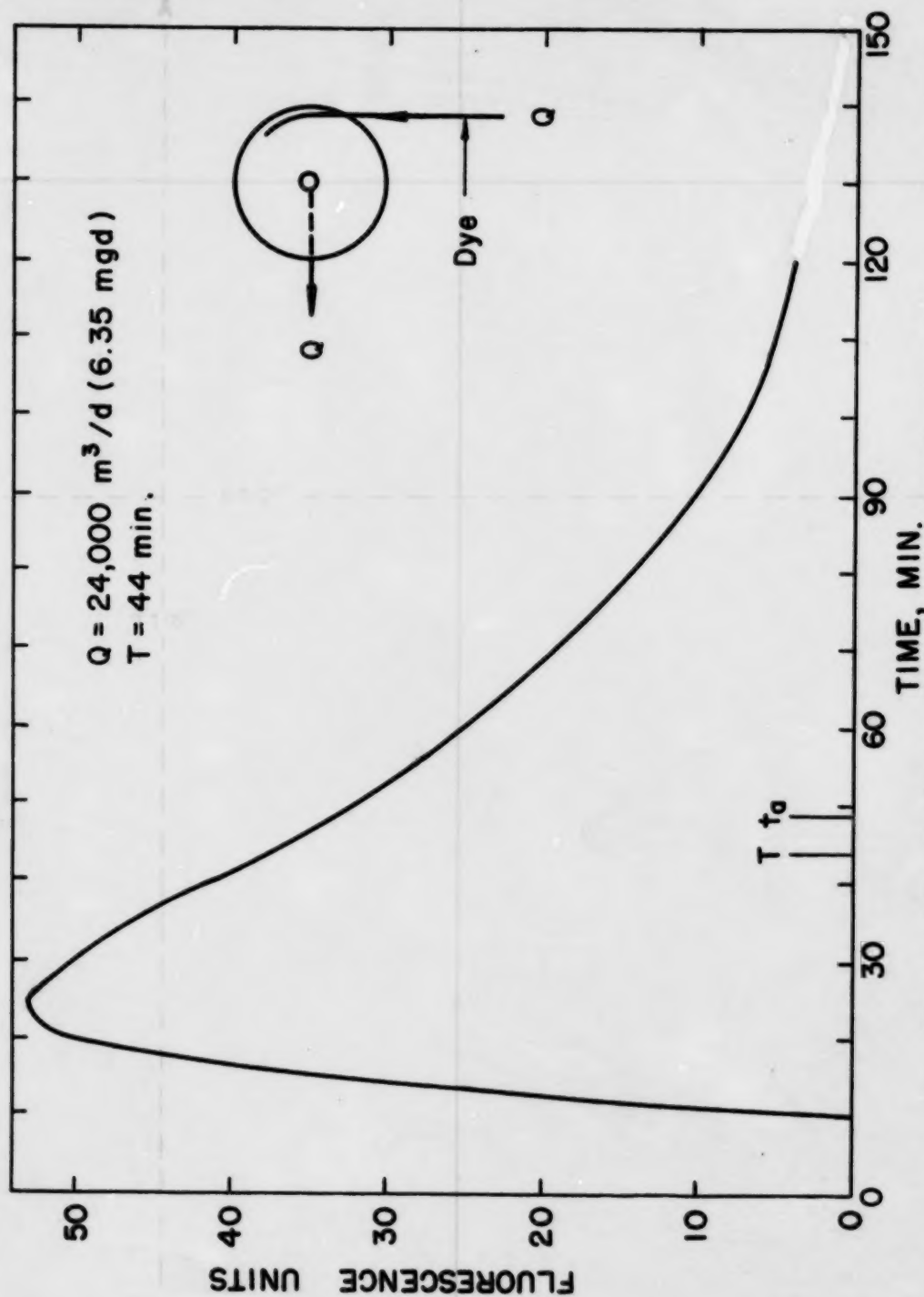


Figure 4. Residence Time Distribution, San Leandro.

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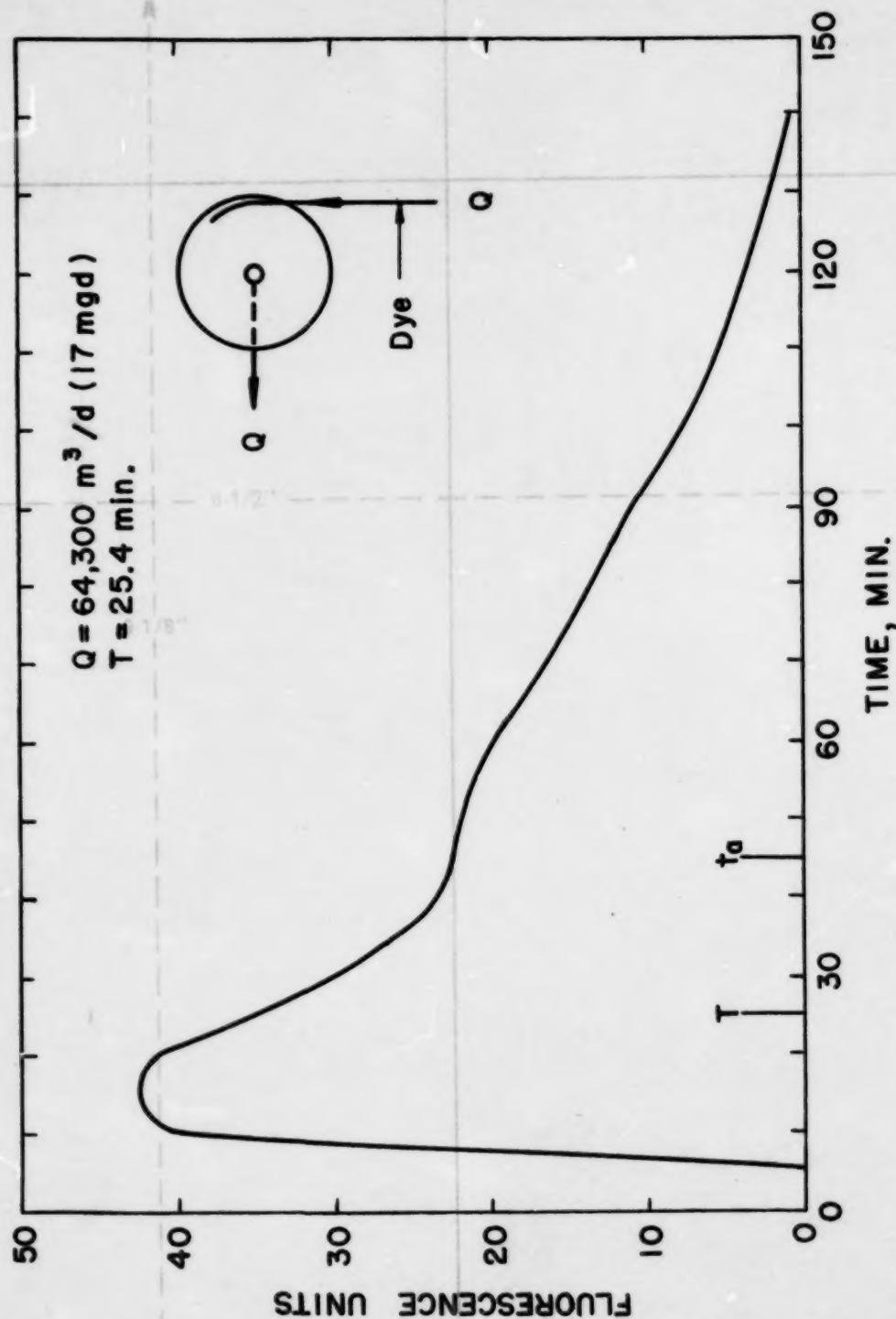


Figure 5. Residence Time Distribution, South San Francisco.

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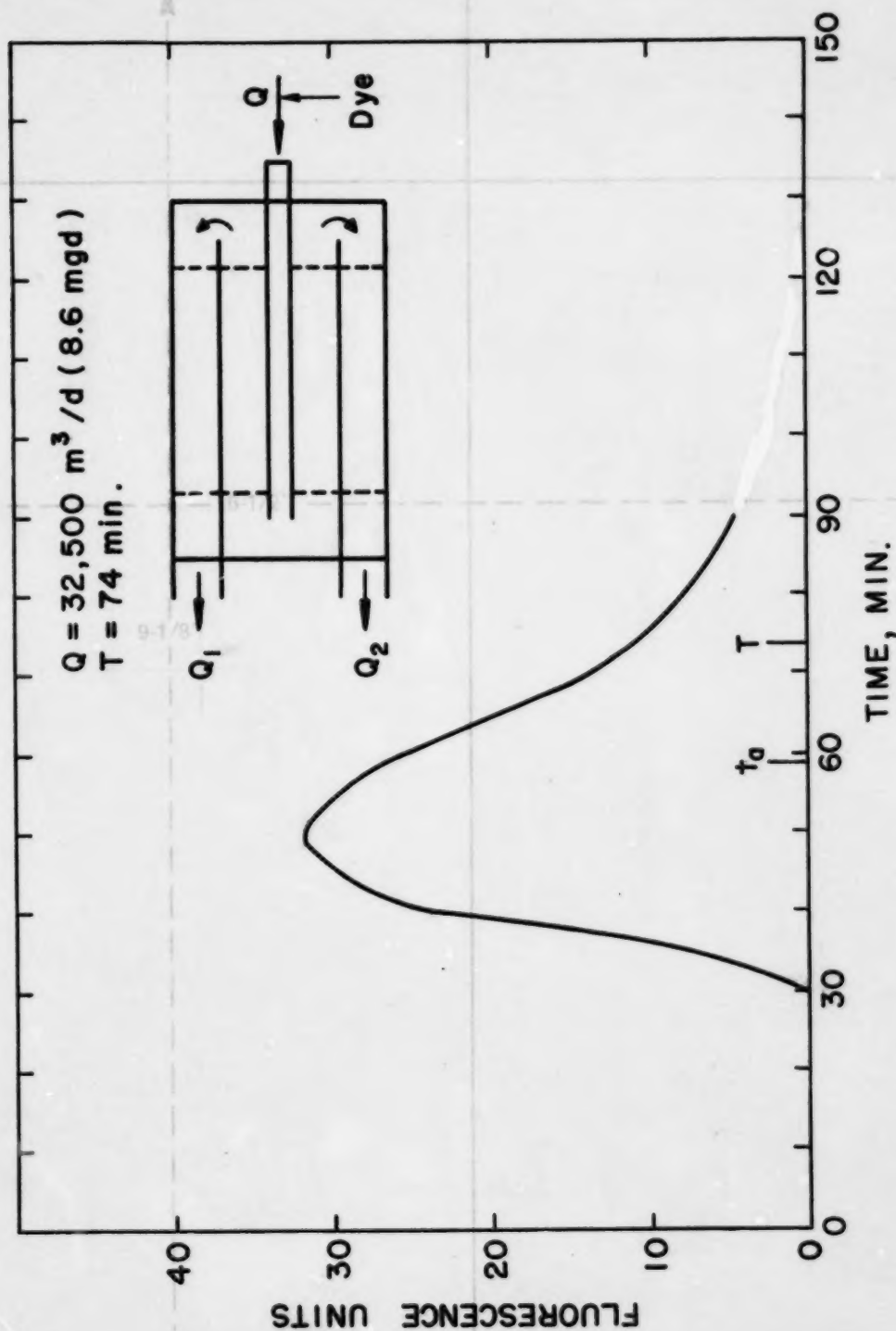


Figure 6. Residence Time Distribution, San Pablo.

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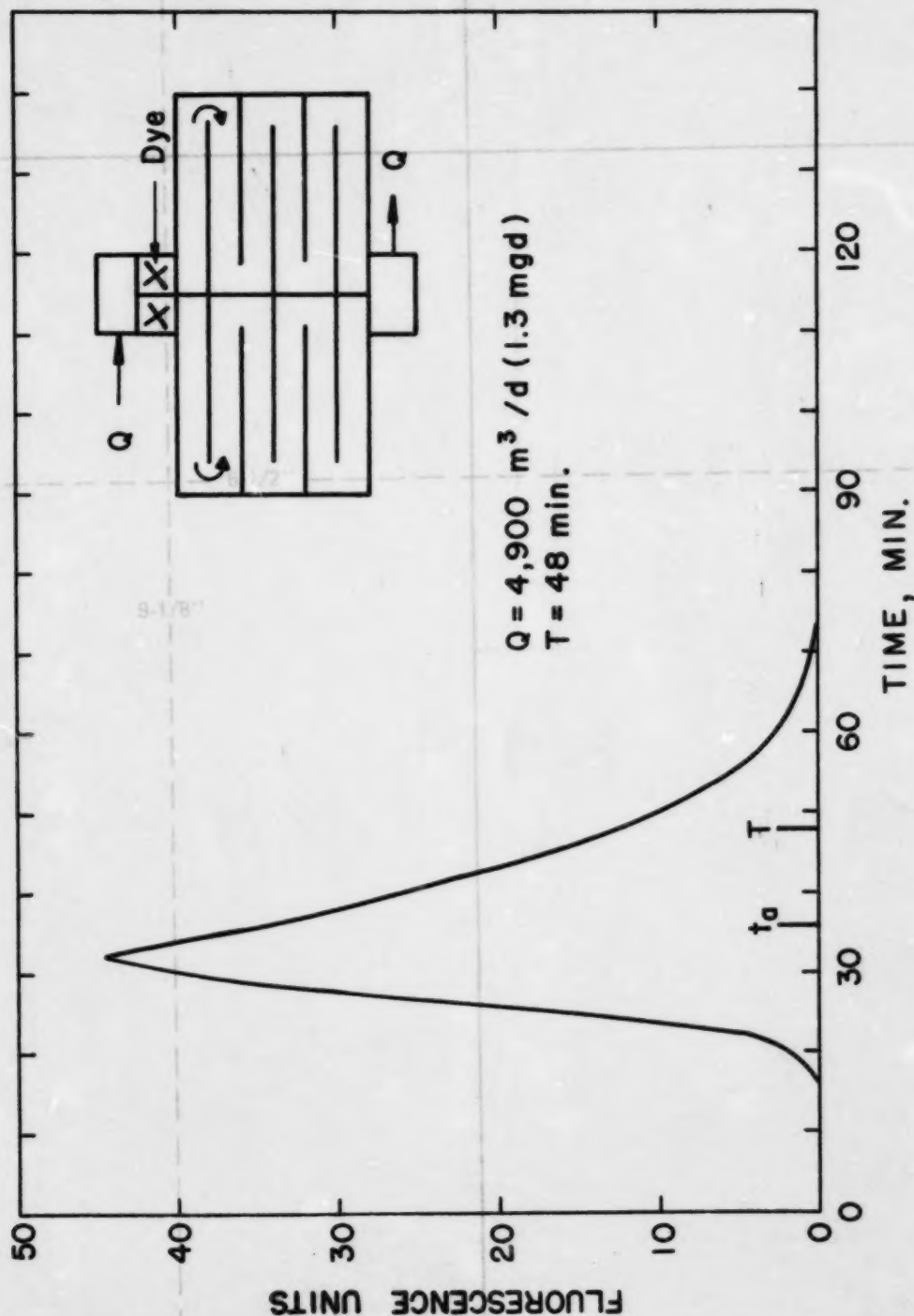


Figure 7. Residence Time Distribution, Plnole.

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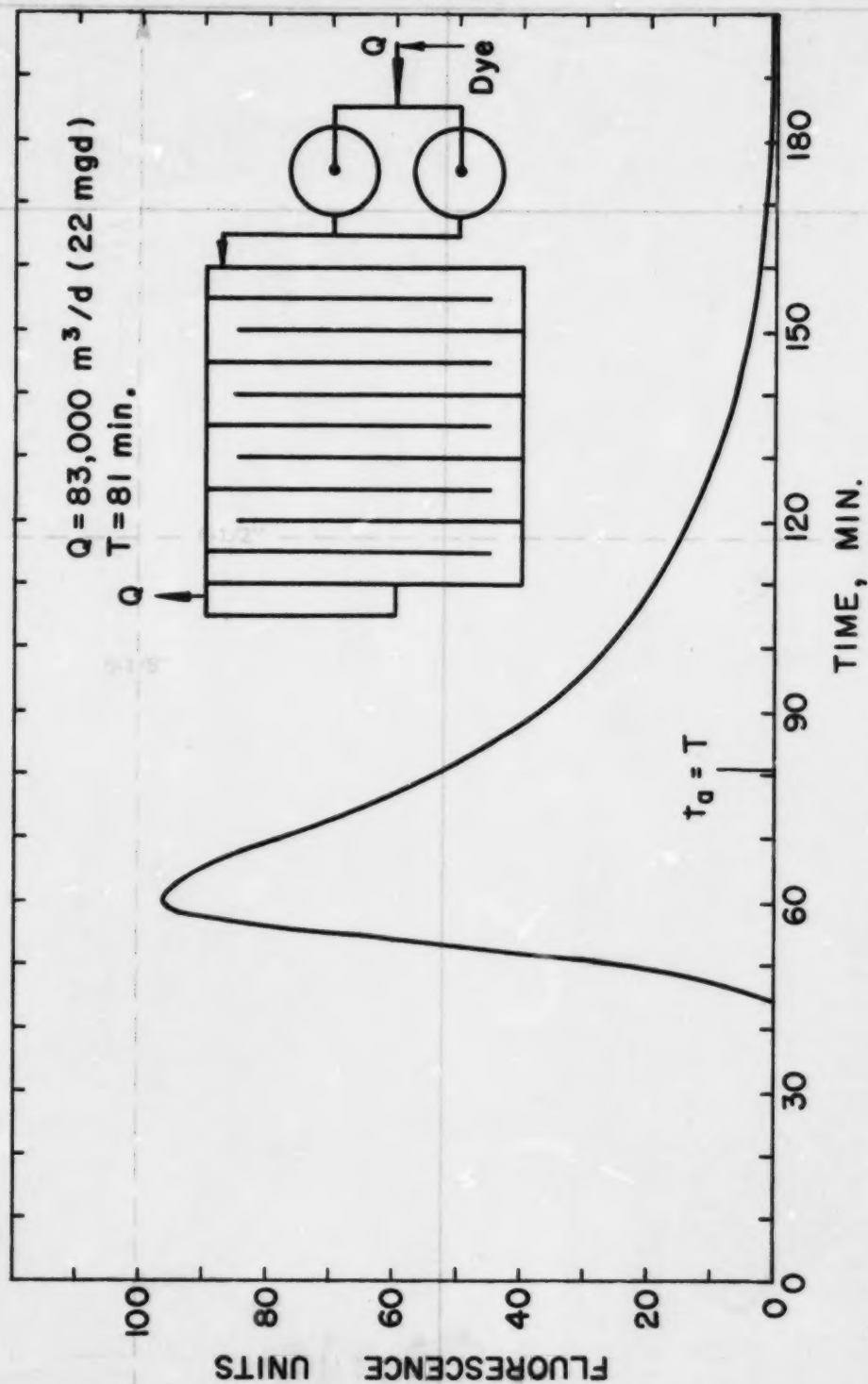


Figure 8. Residence Time Distribution, Sacramento CSD.

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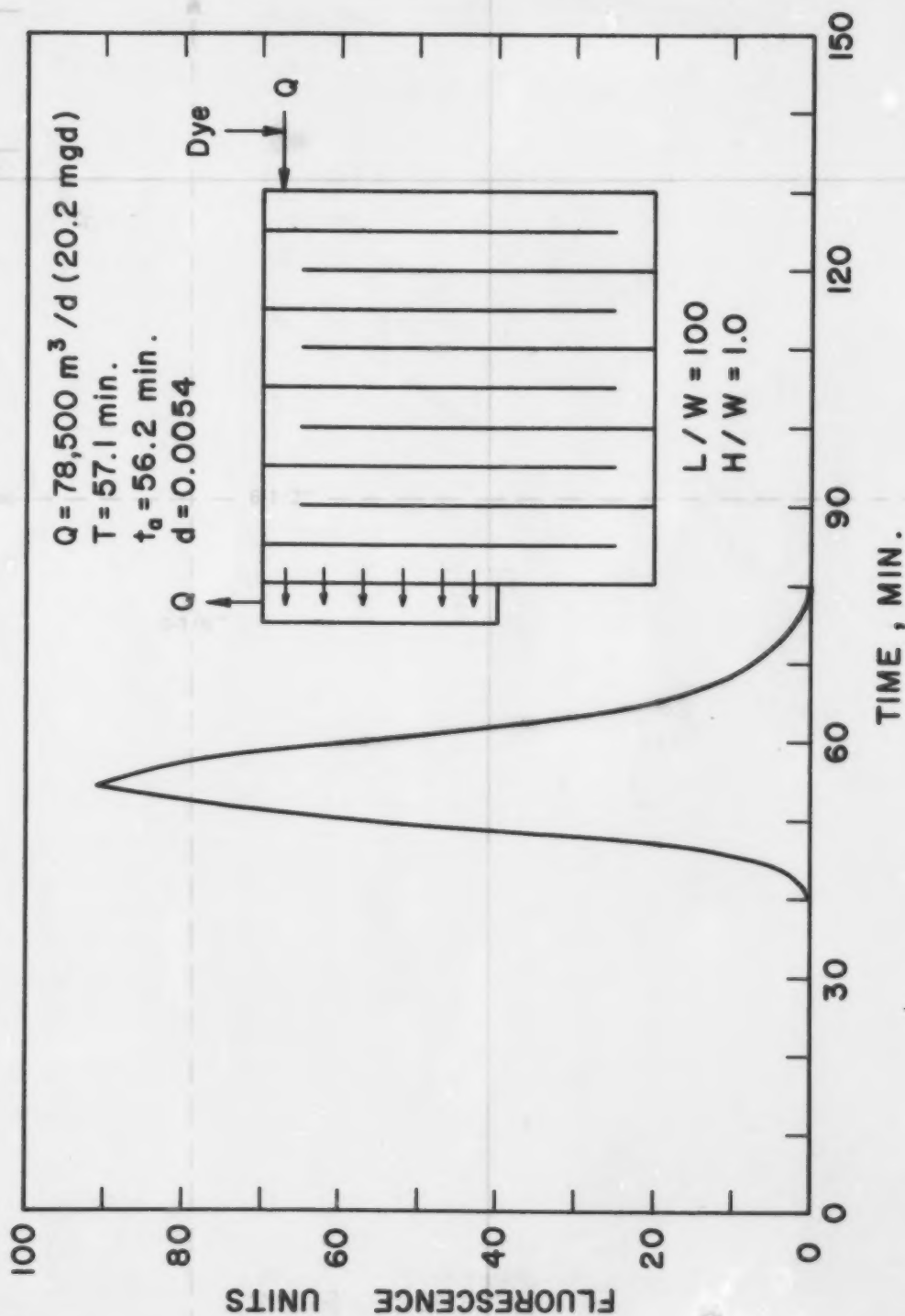


Figure 9. Residence Time Distribution, Sacramento CSD Baffled Tank.

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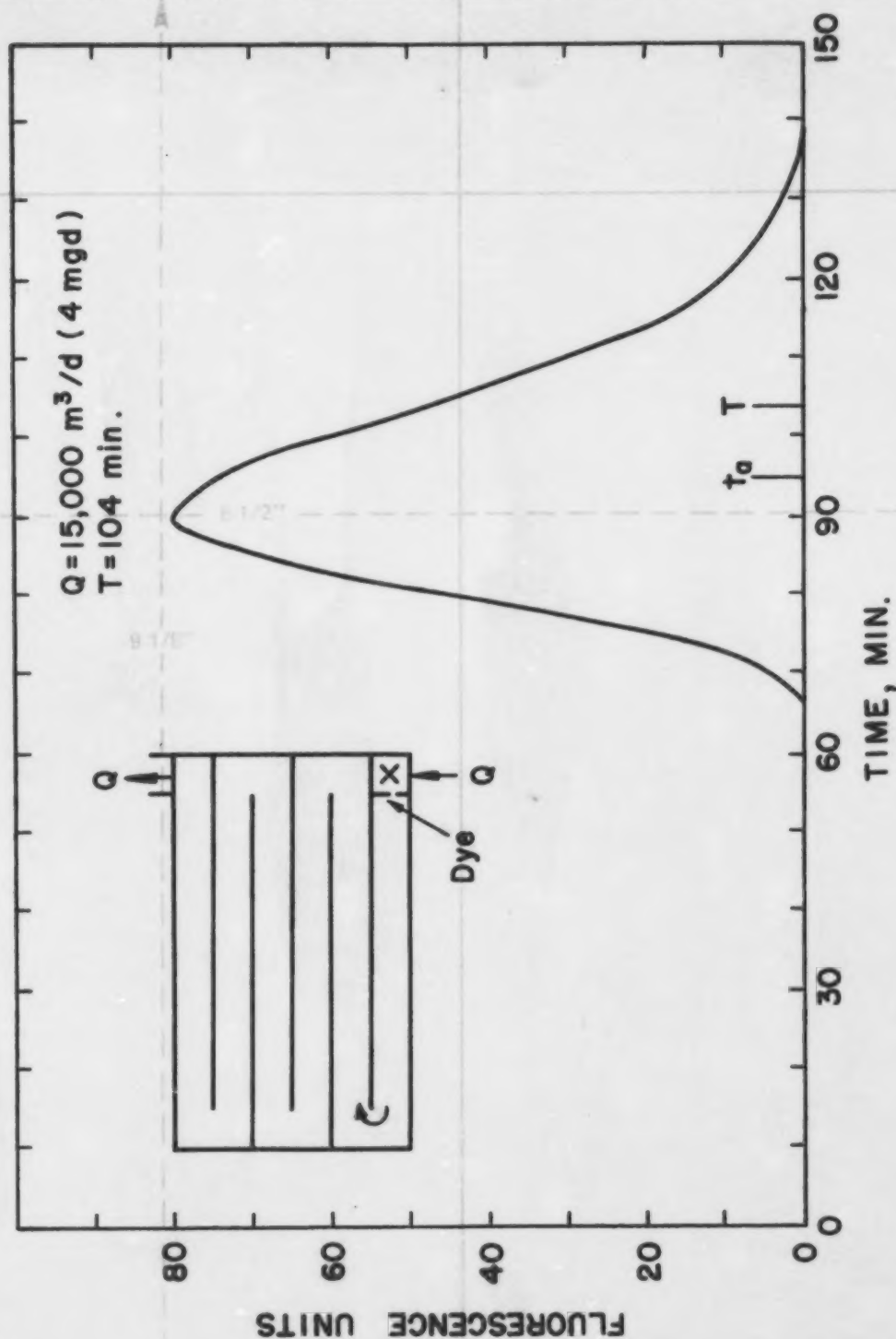


Figure 10. Residence Time Distribution, Roseville.

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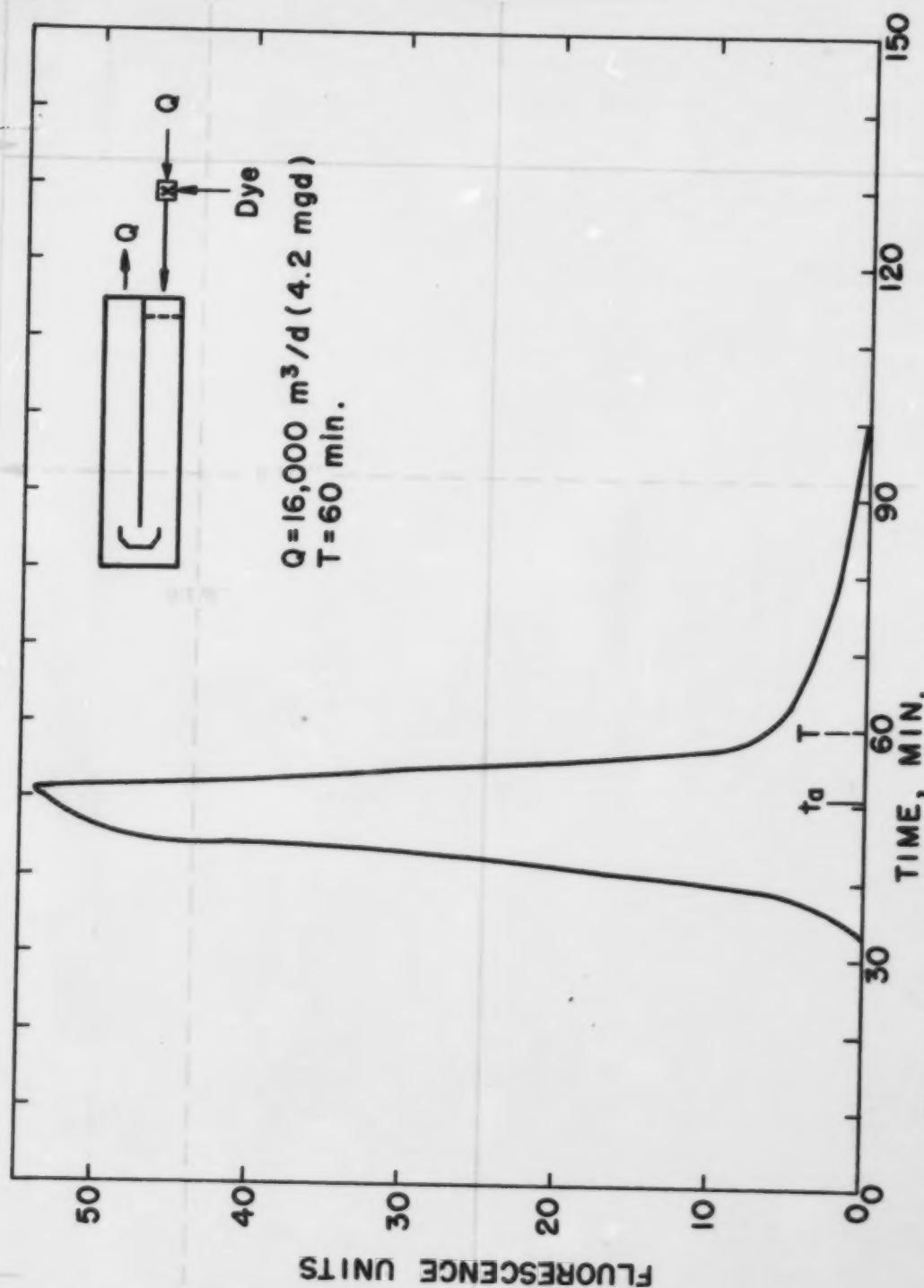


Figure II. Residence Time Distribution, Dublin-San Ramon.

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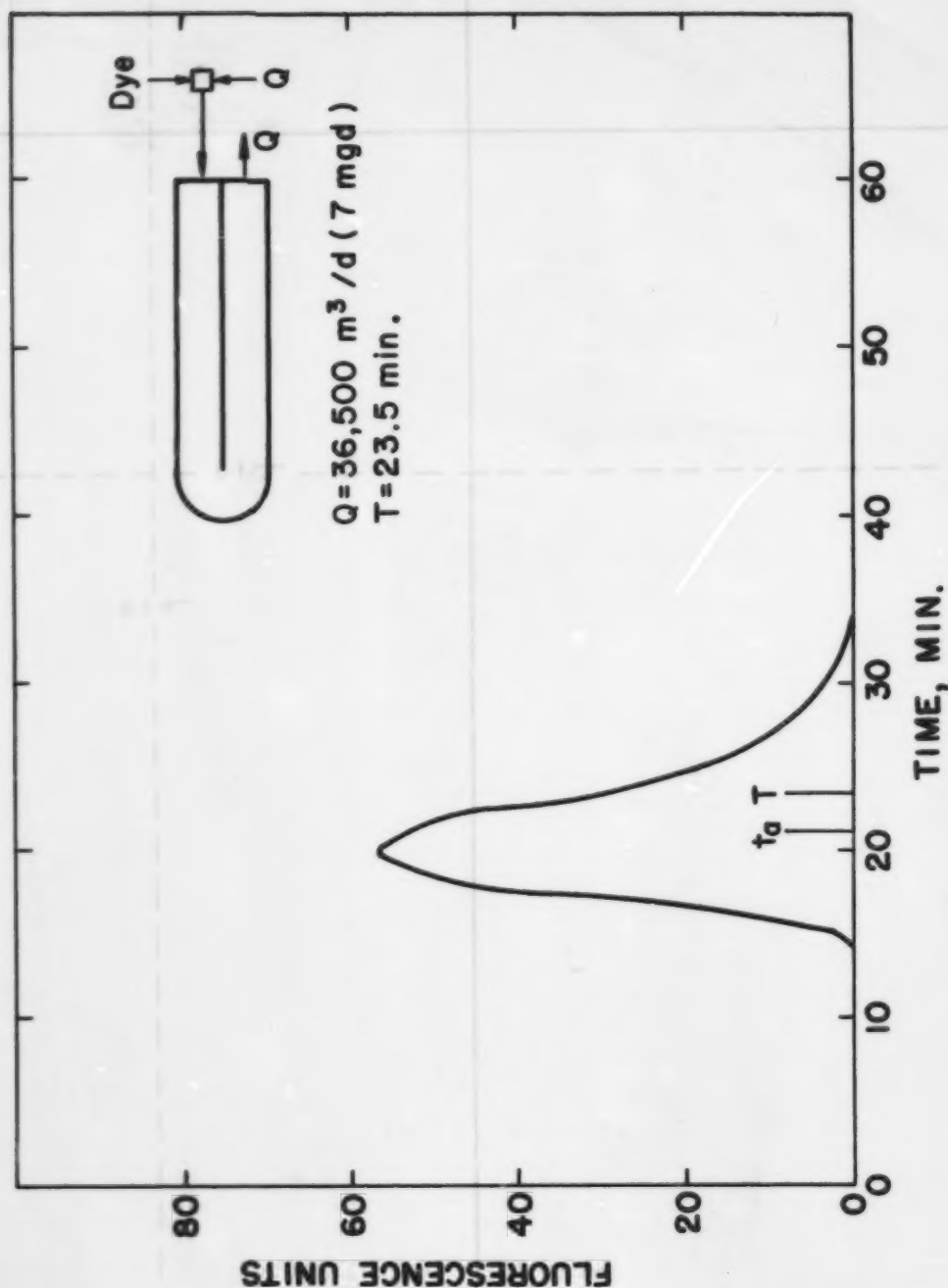


Figure 12. Residence Time Distribution, Ross Valley.

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Table 5. CHLORINE CONTACT TANK DISPERSION DATA

Treatment Plant	L/W	H/W	t_i/T	t_m/T	t_a/T	d	T min. ^a
San Leandro	—	—	0.23	0.57	1.11	0.170	44
San Pablo	15	0.6	0.40	0.68	0.80	0.038	74
Pinole	40	1.0	0.35	0.66	0.76	0.029	48
So. San Francisco	—	—	0.24	0.75	1.80	0.260	25
Sacramento N.E.	—	—	0.54	0.74	1.00	0.050	81
Roseville	60	1.0	0.65	0.87	0.92	0.008	104
Dublin-San Ramon	22	1.0	0.66	0.89	0.89	0.0085	60
Ross Valley S.D.	42	0.2	0.77	0.85	0.90	0.010	23
Pilot Plant	135	2.0	0.63	0.82	0.94	0.023	60
Pilot Plant	270	2.0	0.71	0.92	1.03	0.021	120

^aAt time of test.

From Table 5 it can be seen that the length-to-width ratio (L/W) does not adequately describe plug flow characteristics. The pilot tank had a much higher L/W ratio than the full-scale tanks but did not have a correspondingly smaller dispersion number. Other studies (2,16,17) have indicated that the dispersion number usually decreases with increasing L/W ratio although the correlation is poor. Apparently factors other than L/W ratio play a role here, such as the depth-to-width ratio (H/W) and the extent of dead space. It appears from the data that the H/W ratio should be 1.0 or less.

Another factor which may influence contact tank design is the flow velocity. All the full-scale baffled tanks had average flow velocities greater than 105 cm/min (3.5 ft/min.) at peak flow, whereas the pilot tank had a flow velocity of only 46 cm/min. (1.5 ft/min). An adequate flow velocity may help to keep the suspended solids in suspension and reduce dead spaces.

Figures 4 and 5 are the tracer curves of two spirovortex tanks. These curves are typical of a completely mixed system. Of interest here is the very short t_i value which indicates considerable short-circuiting of effluent. On the other hand, the average contact time, t_a , is markedly higher than the theoretical detention time T, which appears to be due to the recycling of dye from dead spaces. The only advantage the spirovortex has is that it helps to keep the solids in suspension by its circular motion. Both plants using the spirovortex tank had severe sludge carryover problems which would have clogged up a plug flow type tank. One disadvantage of this configuration is indicated by the long tail of the curve, which is caused primarily

by the dead spaces. It has been reported (5,10) that at longer contact times the combined chlorine residual begins to convert to organic chloramines which have low germicidal efficiency. These converted residuals may dilute the effect of the fresh residual when backmixed from the dead spaces into the system.

Figure 6 describes a contact tank with once-around longitudinal baffles and an L/W ratio of 15. This system has four grid type cross baffles in each tank which help to distribute the flow and reduce short-circuiting.

Figure 7 describes a serpentine baffled tank with an L/W ratio of 40. The t_i value, however, is only about 15 minutes because there is leakage through the corrugated fiberglass baffles and through a 150 mm (6-inch) channel which runs crosswise through the bottom of the tank.

Figure 8 describes a chlorine contact system consisting of two circular tanks, resembling clarifiers, in parallel followed by a serpentine baffled tank which has an L/W ratio of 100. The overall dispersion characteristics are fairly good with the exception of the long tail caused by the circular tanks. The minimum contact time in the circular tanks was only 4 minutes; thus the circular tanks mainly had the effect of increasing the average detention time. Figure 9 shows the results of a dye test done on the baffled tank only. Evidently this tank has excellent plug flow characteristics, and the system might be improved by bypassing the circular tanks. The plant personnel, however, reported that good sludge removal was obtained in the circular tanks. Apparently the circular tanks were the original contact tanks, and the baffled tank was added later as flows increased.

Figure 10 depicts a serpentine baffled tank with good plug flow characteristics. However, there is no scum removal mechanism which resulted in a layer of scum and greaseballs in the tank during plant upset.

Figures 11 and 12 show the tracer curves for two once-around baffled tanks which have good plug flow characteristics. The tank shown on Figure 11 has an L/W ratio of only 22:1. This tank has a perforated baffle at the inlet and a turning baffle at the 180° turn. The good plug flow characteristics of this tank may be due to the good baffling. The tank shown in Figure 12 has approximately 40 percent of its total contact time in the conduits leading to the tank. Although the plug flow characteristics are good, the contact time provided (t_i = 15 minutes) is too short to provide adequate disinfection with reasonable chlorine dosage.

Due to the variations in flow rates the chlorine contact times of the full-scale plants varied diurnally, whereas the contact time on the pilot plant remained constant. Diurnal flow rate variations were not measured. However, the normal ratio of daily maximum flow to daily mean flow is 2.5:1 at wastewater treatment plants (20). During the daytime sampling period, the standard deviation of the calculated detention times, expressed as a percentage of the mean theoretical detention, was 22 - 24 percent at South San Francisco and Dublin-San Ramon, 47.5 percent at Ross Valley, and 8-12 percent at the remaining plants.

Inasmuch as the overall performance of the pilot system was better than that of the full-scale systems, it would appear from Table 5 that a dispersion number of 0.02 is adequate for chlorine contact tanks, provided that an adequate t_i is also

present. However, at the present state of knowledge the dispersion number of a tank is not known beforehand and the correlation of d with L/W ratio is poor. Evidently more research is necessary in this area.

CHLORINE RESIDUAL-CONTACT TIME RELATIONSHIPS

The coliform bacteria survival ratios (N_1/N_0) were plotted against the product of the chlorine residual and detention time ($R \times T$) on double log graphs in order to evaluate the relative efficiencies of disinfection at each plant. This corresponds to the equation $N_1/N_0 = (RT/b)^n$ which was presented in Section 2. The plots are shown on Figures 13 to 28 for both the optimized pilot plant and the full-scale plant at each location. The baffled tank on the pilot plant was used in all of these studies. The raw data are shown in Tables A-1 to A-8 in the Appendix. Each point on the graphs represents a daily median value of eight coliform samples. The points shown with arrows mean "less than the indicated value." The dashed line represents the theoretical plug flow curve with a slope of -3 , whereas the solid line is the actual regression curve. Table 6 shows a least squares regression analysis of the same data. In addition to constants b and n , the table shows the correlation coefficient, r , and the F statistic. The F statistic is used to determine whether the relationship is statistically significant, or if it occurred by chance alone. A level of 0.05 is considered significant, and a level of 0.01 highly significant. The values shown were provided by the computer. As explained before, b is the X -intercept when $N_1/N_0 = 1.0$, and n is the slope.

As seen from Table 6 seven of the 8 pilot plant curves and 6 of the 8 full-scale plant curves are statistically significant. The curves of the full-scale data with the exception of South San Francisco and Ross Valley, have numerically smaller slopes than those of the pilot plant. This is primarily due to design deficiencies in the full scale plants. The South San Francisco results are anomalous. They were apparently due to the very poor chlorine control system and the sludge overflows. Since the primary objective of the project was to do the comparative studies discussed previously, and since incubator space was limited, most of the full-scale plant samples were taken at the effluent end of the contact tank and, with the exception of Dublin-San Ramon, the number of samples taken at the influent end was limited. More reliable curves would have been obtained by concurrently taking equal number of samples at both ends and at the midpoint of the tank.

As seen from Table 6, the slope n and the intercept b are different for each effluent. The differences in the pilot plant curves among the eight plants are independent of design factors and are, therefore, related to water quality. The scatter of the data points is partly due to the fact that the N_0 levels in some effluents varied by a factor of 10 from day to day whereas the N_1 levels remained fairly constant. Other reasons for the scatter are daily alternation of sampling points and inadequate range of detention times used. While much of the individual pilot plant data shown in the Appendix formed curves which approached the -3 slope, it was occasionally observed in the poorer quality effluents that the coliform levels remained constant or went up with increasing contact time. This caused some of the regression curves to flatten out. However, the mean slope of all the pilot curves approaches -3 (Table 6). Note that the pilot plant curves at the three plants practicing nitrification and/or filtration (i.e., San Pablo, Roseville and Dublin-San Ramon) have steep slopes with little scatter in the data. However, as will be explained later,

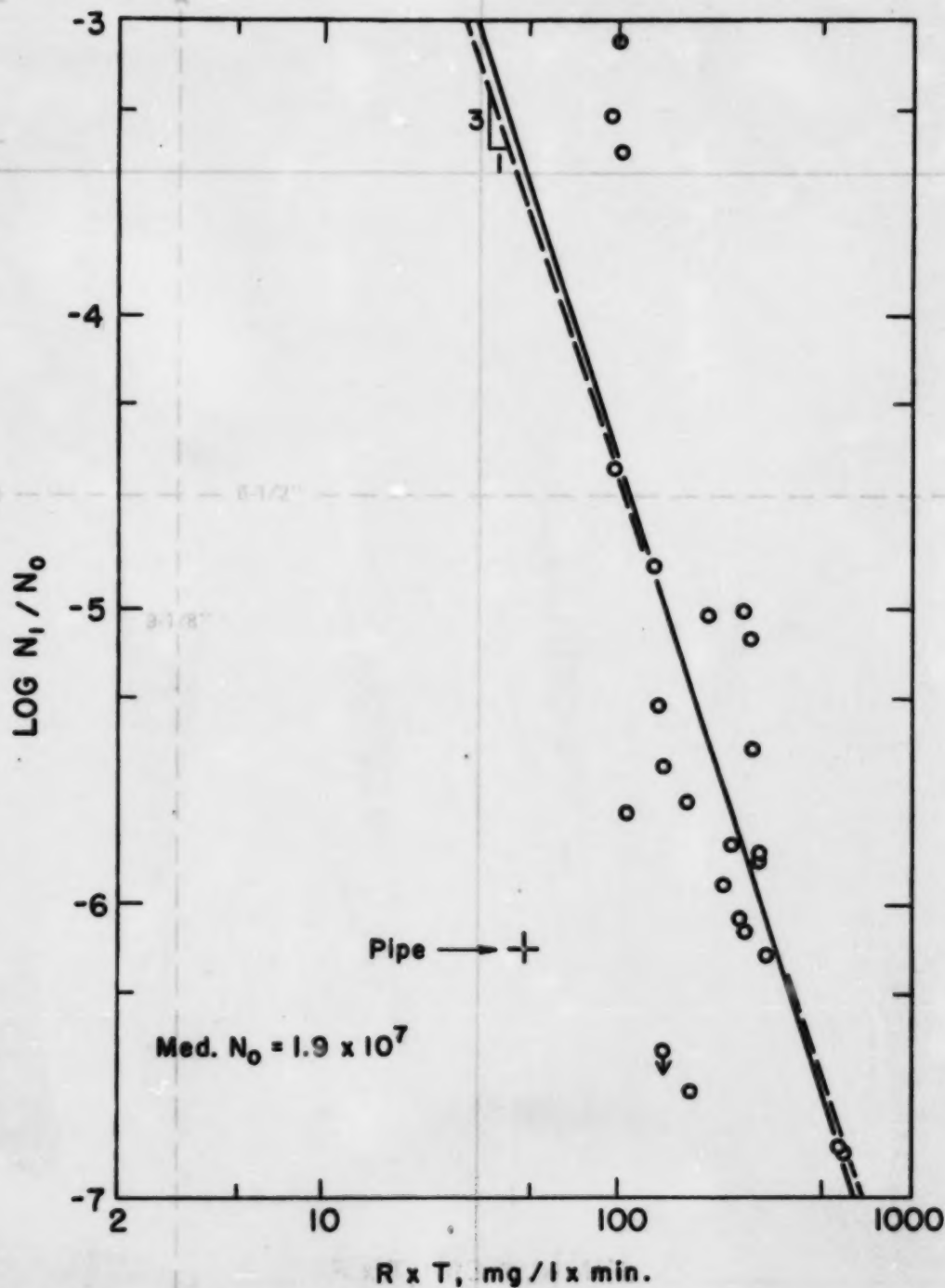
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Figure 13. Coliform Bacteria Survival, Pilot Plant at San Leandro.

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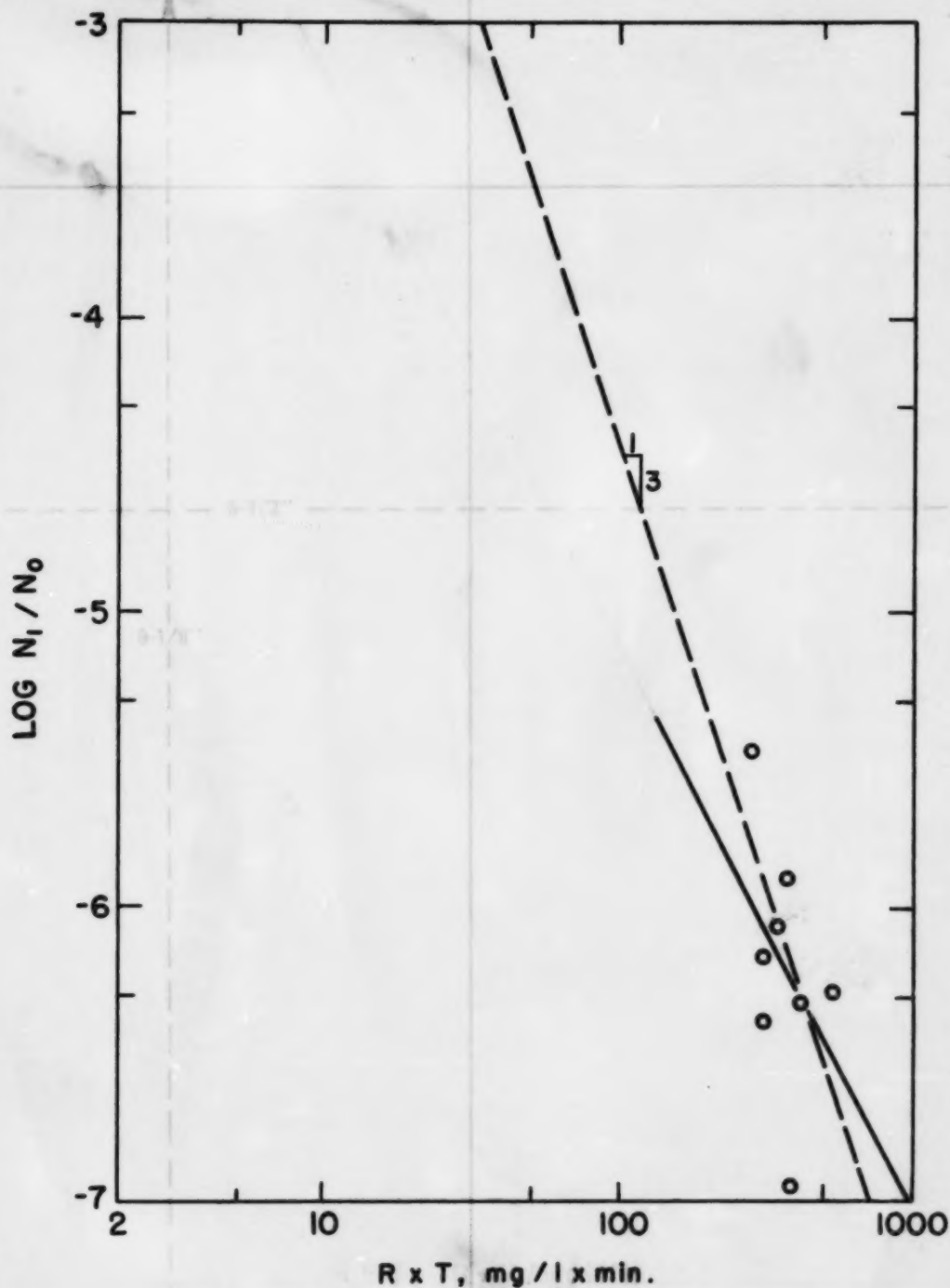


Figure 14. Coliform Bacteria Survival, San Leandro Plant.

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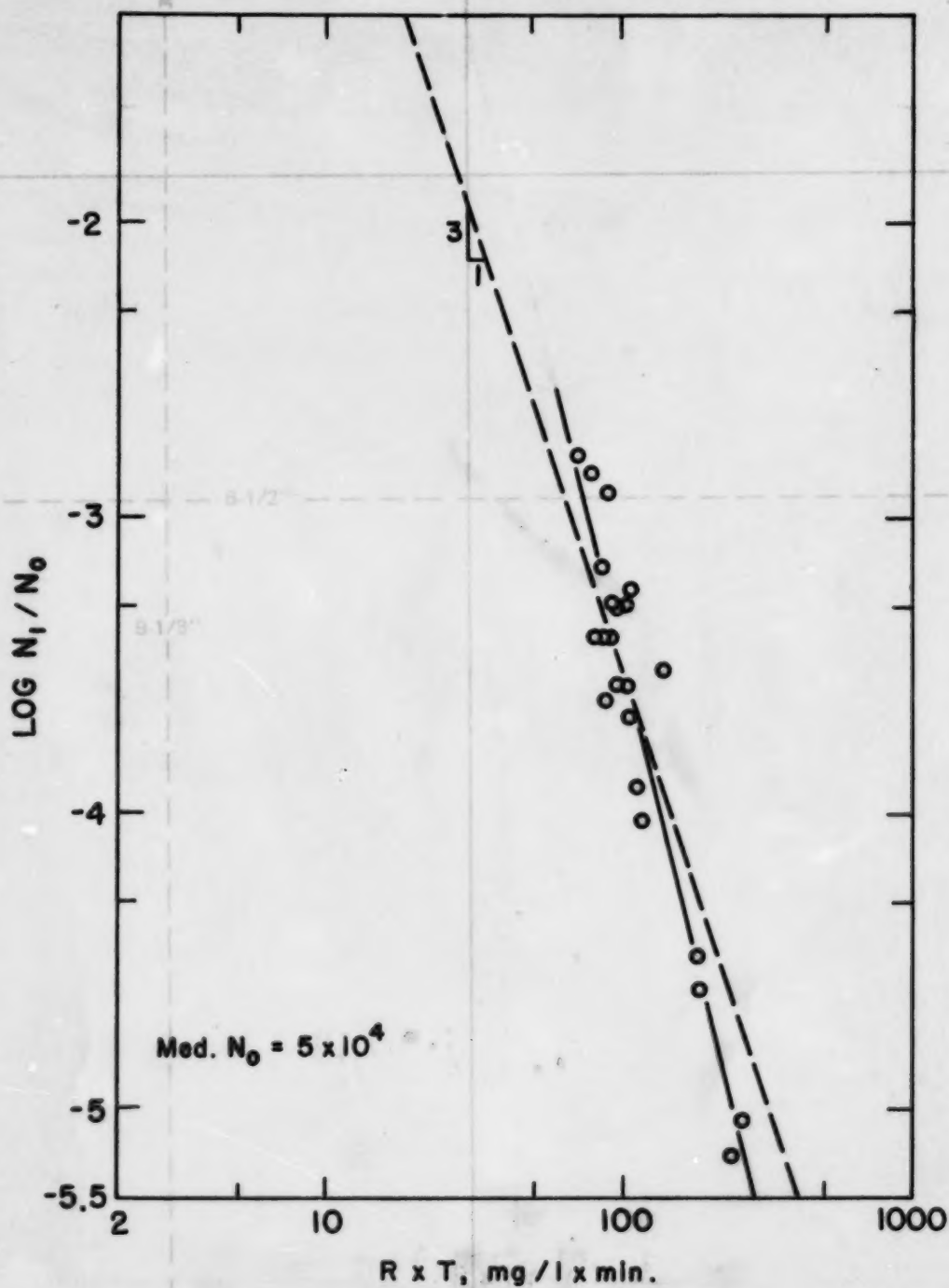


Figure 15. Coliform Bacteria Survival, Pilot Plant at San Pablo.

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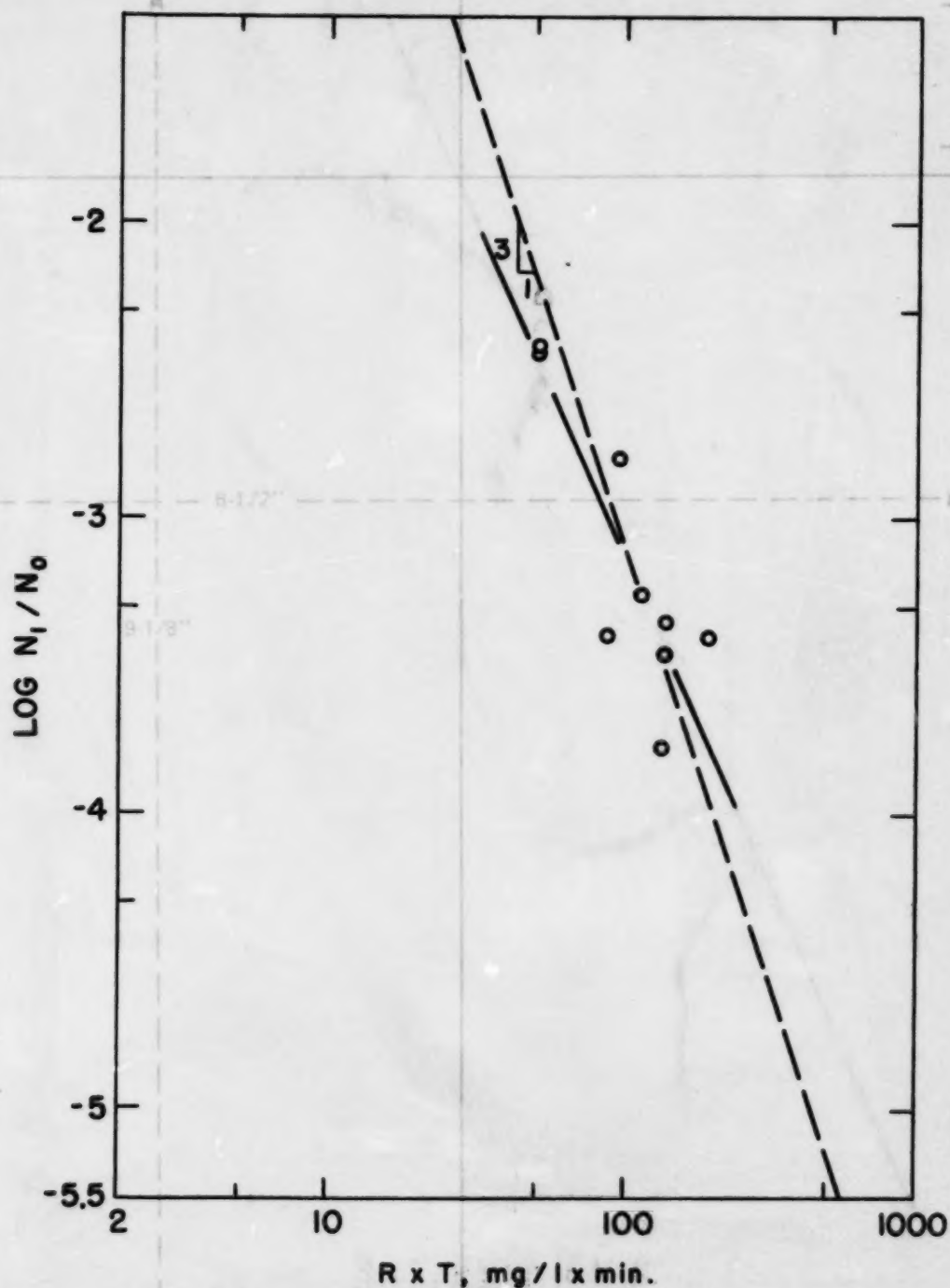
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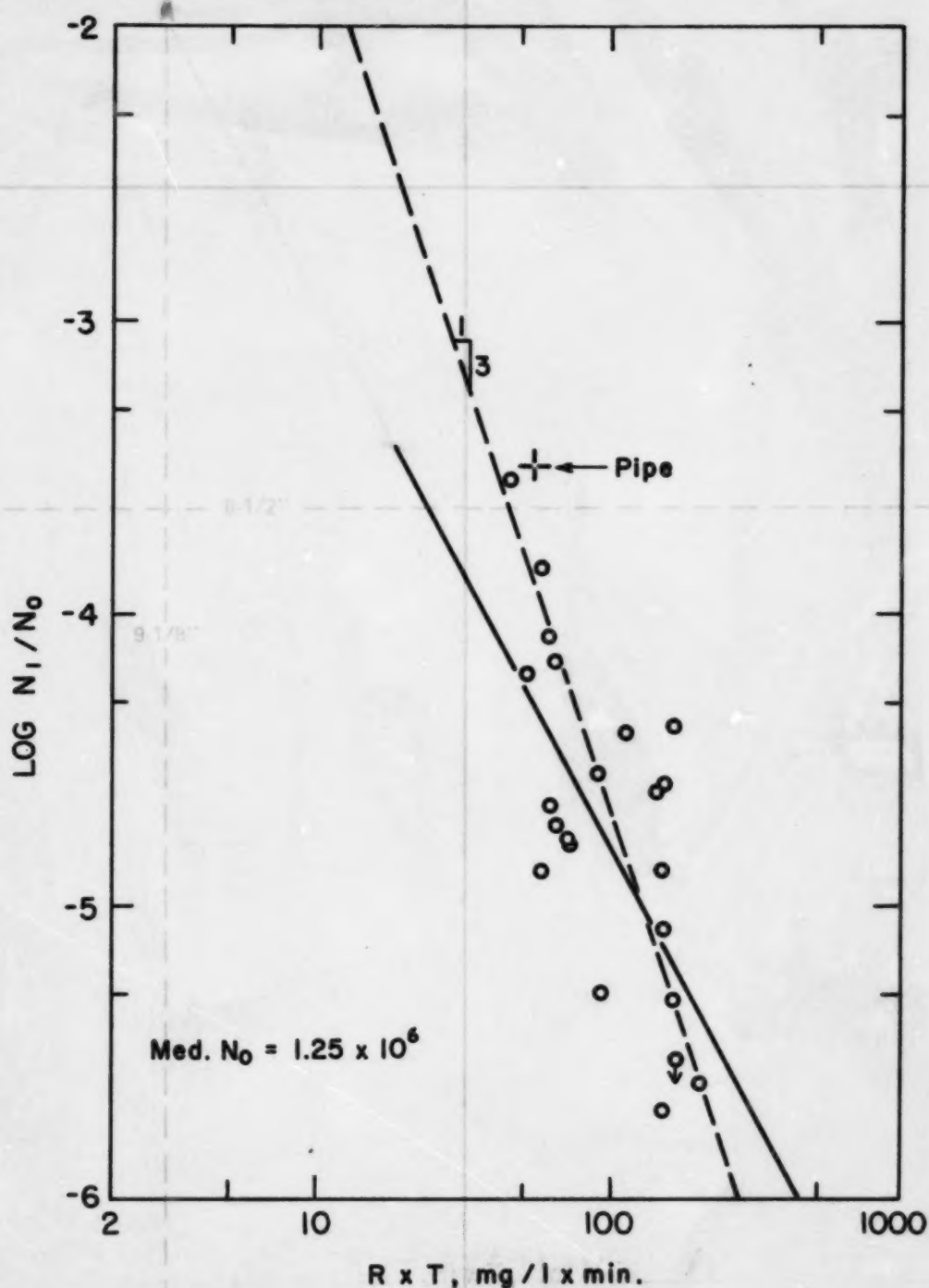
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Figure 17. Coliform Bacteria Survival, Pilot Plant at Pinole.

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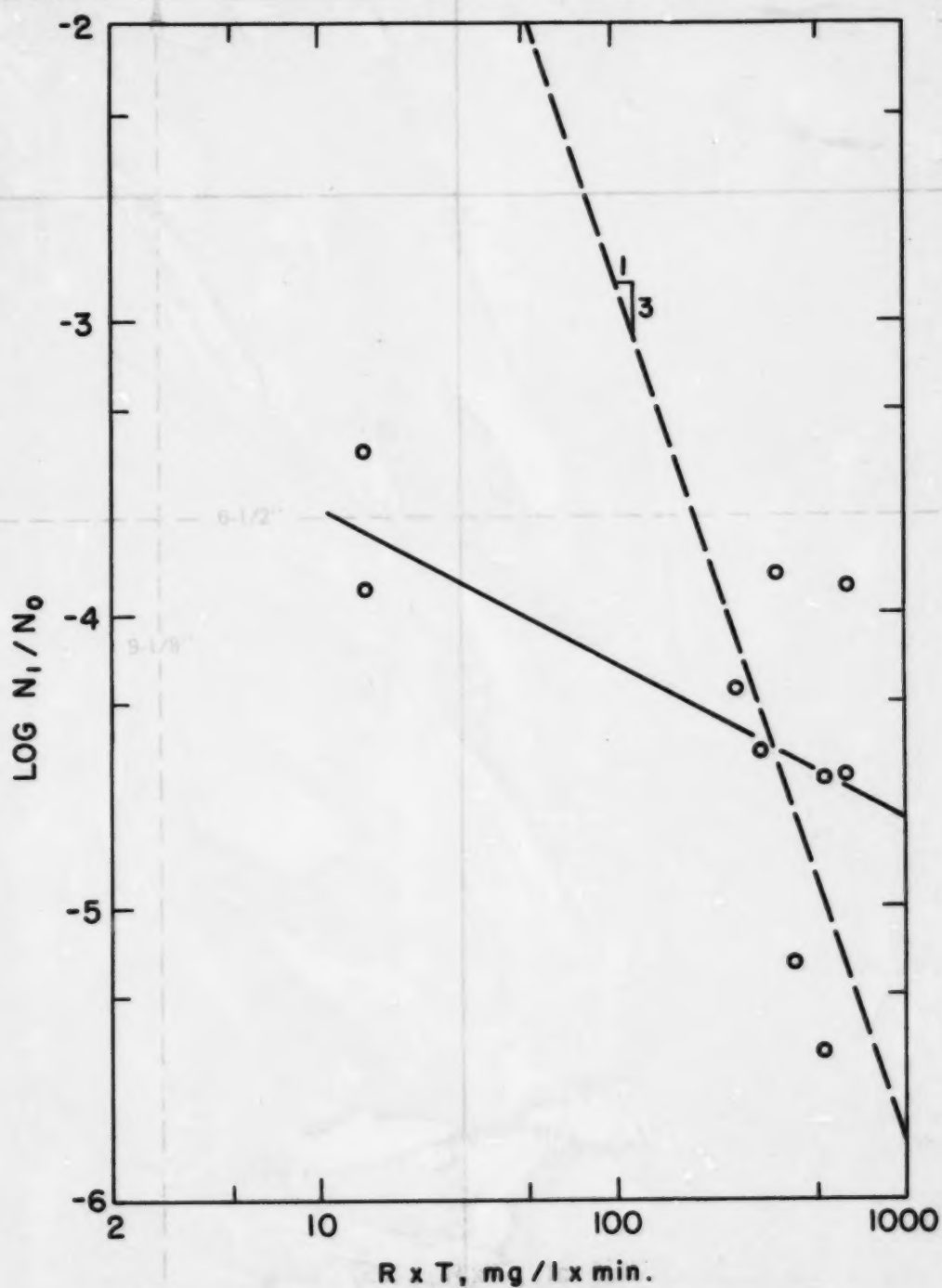


Figure 18. Coliform Bacteria Survival, Pinole Plant.

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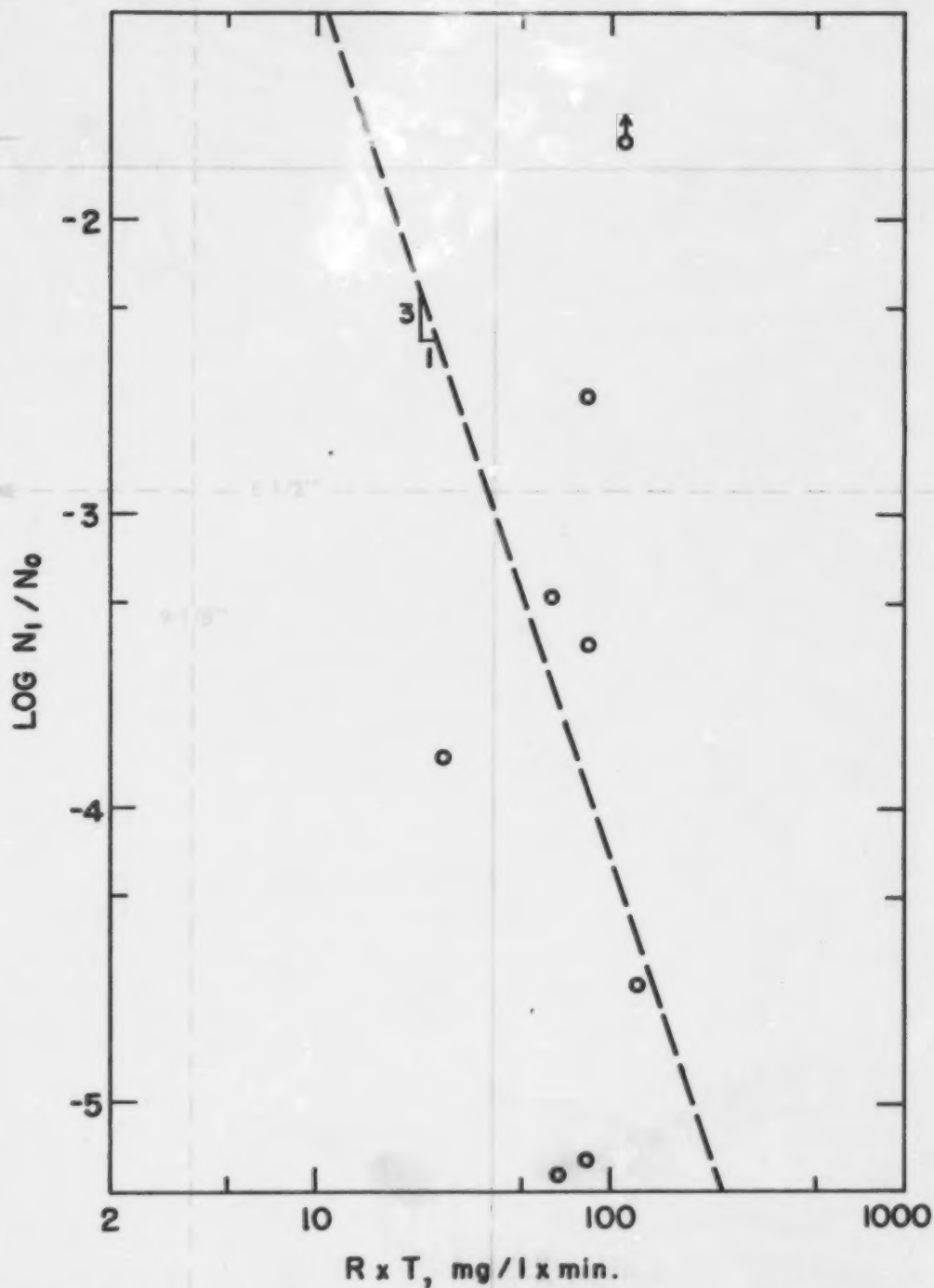


Figure 20. Coliform Bacteria Survival, South San Francisco Plant.

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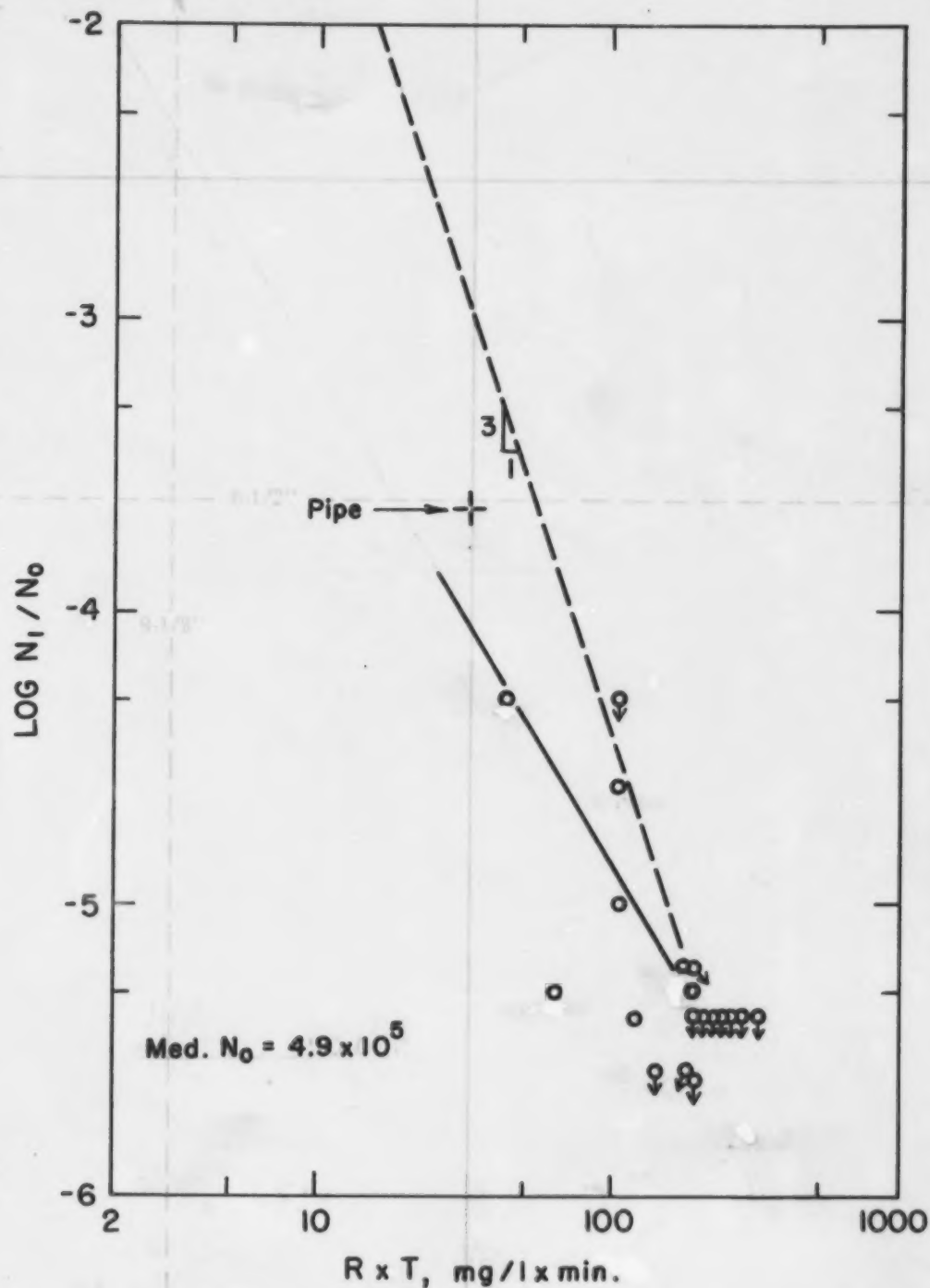
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Figure 21. Coliform Bacteria Survival, Pilot Plant at Sacramento CSD-N.E.

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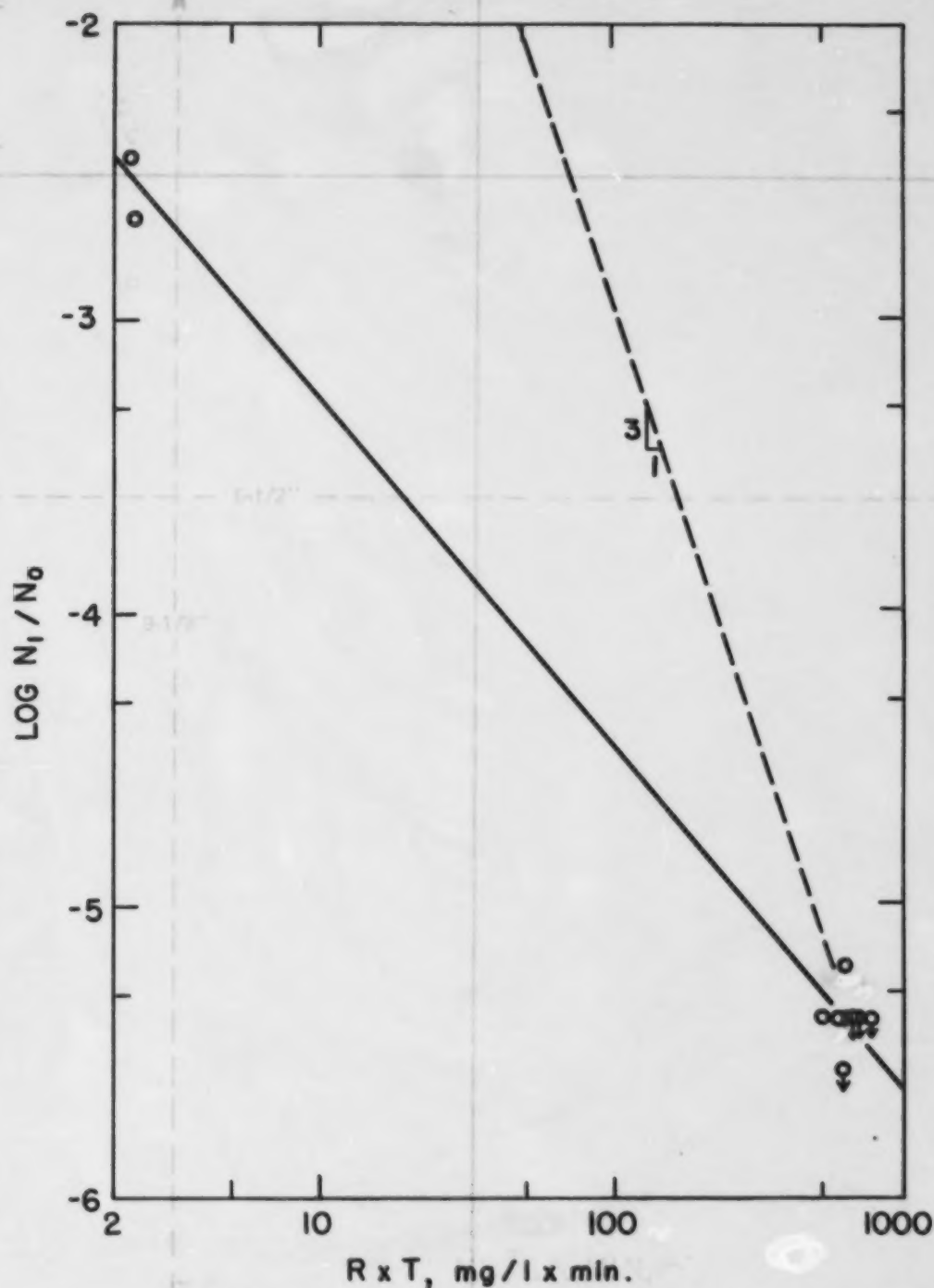


Figure 22. Colliform Bacteria Survival, Sacramento CSD-N.E. Plant.

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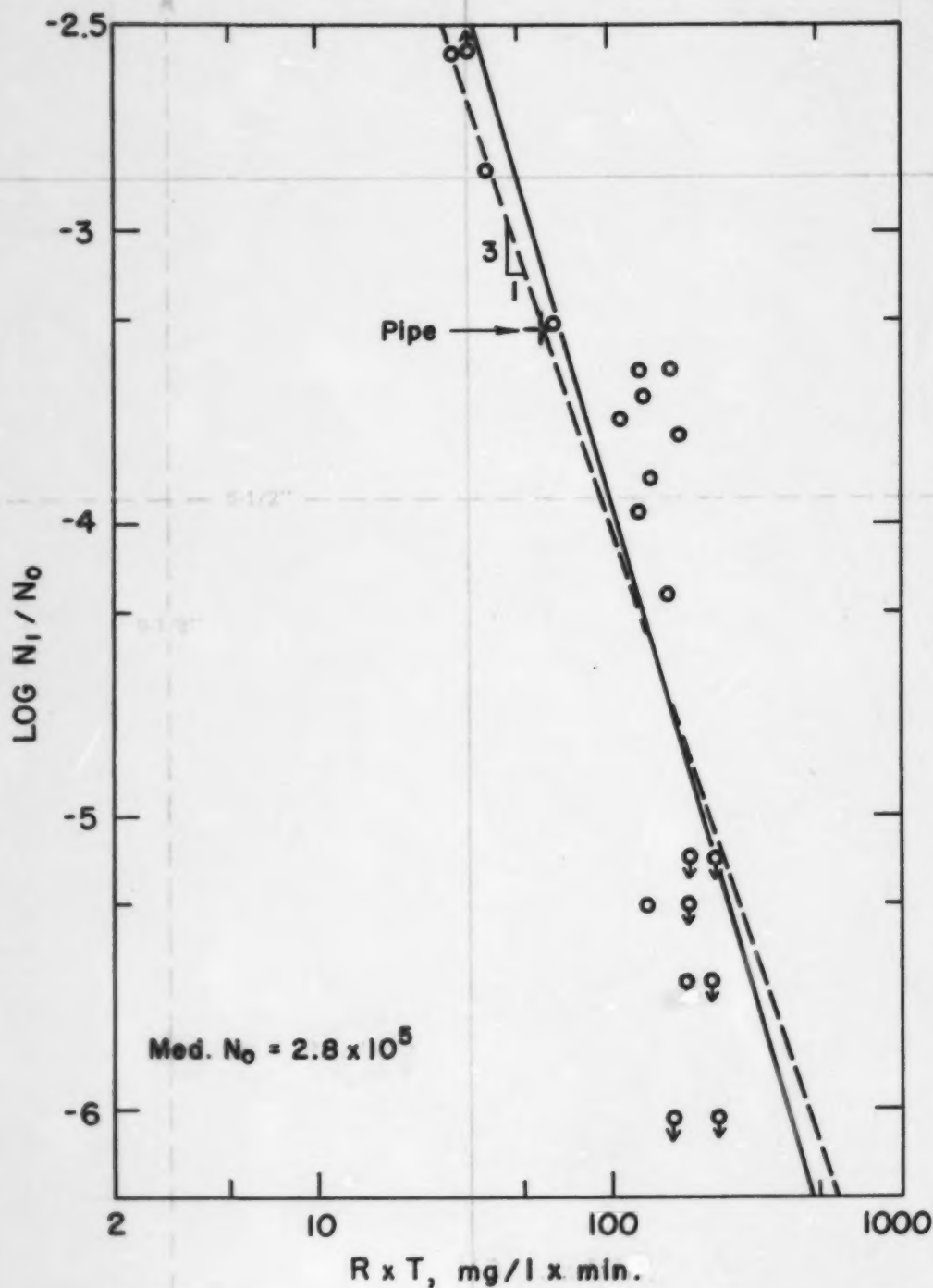


Figure 23. Coliform Bacteria Survival, Pilot Plant at Roseville .

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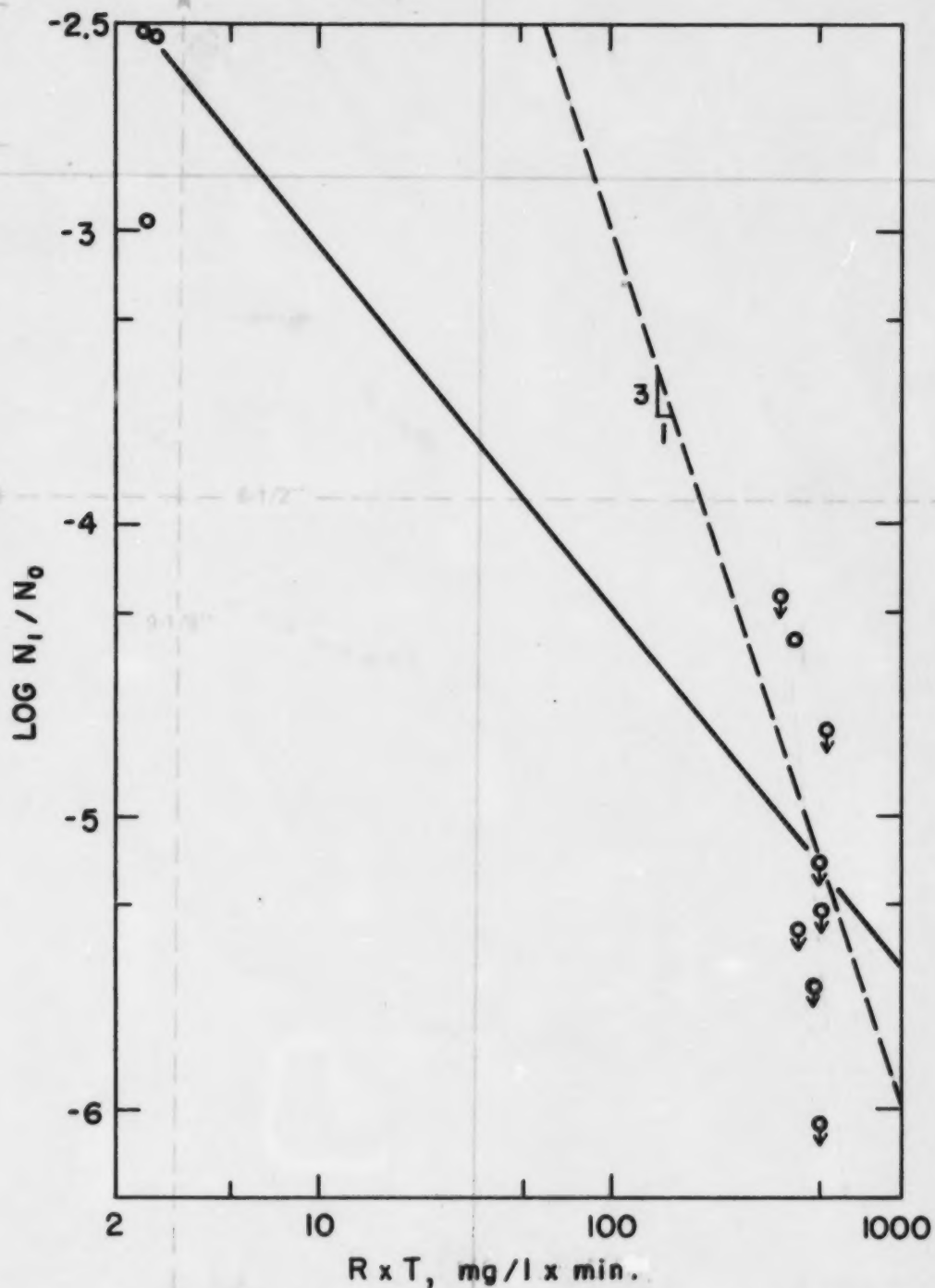
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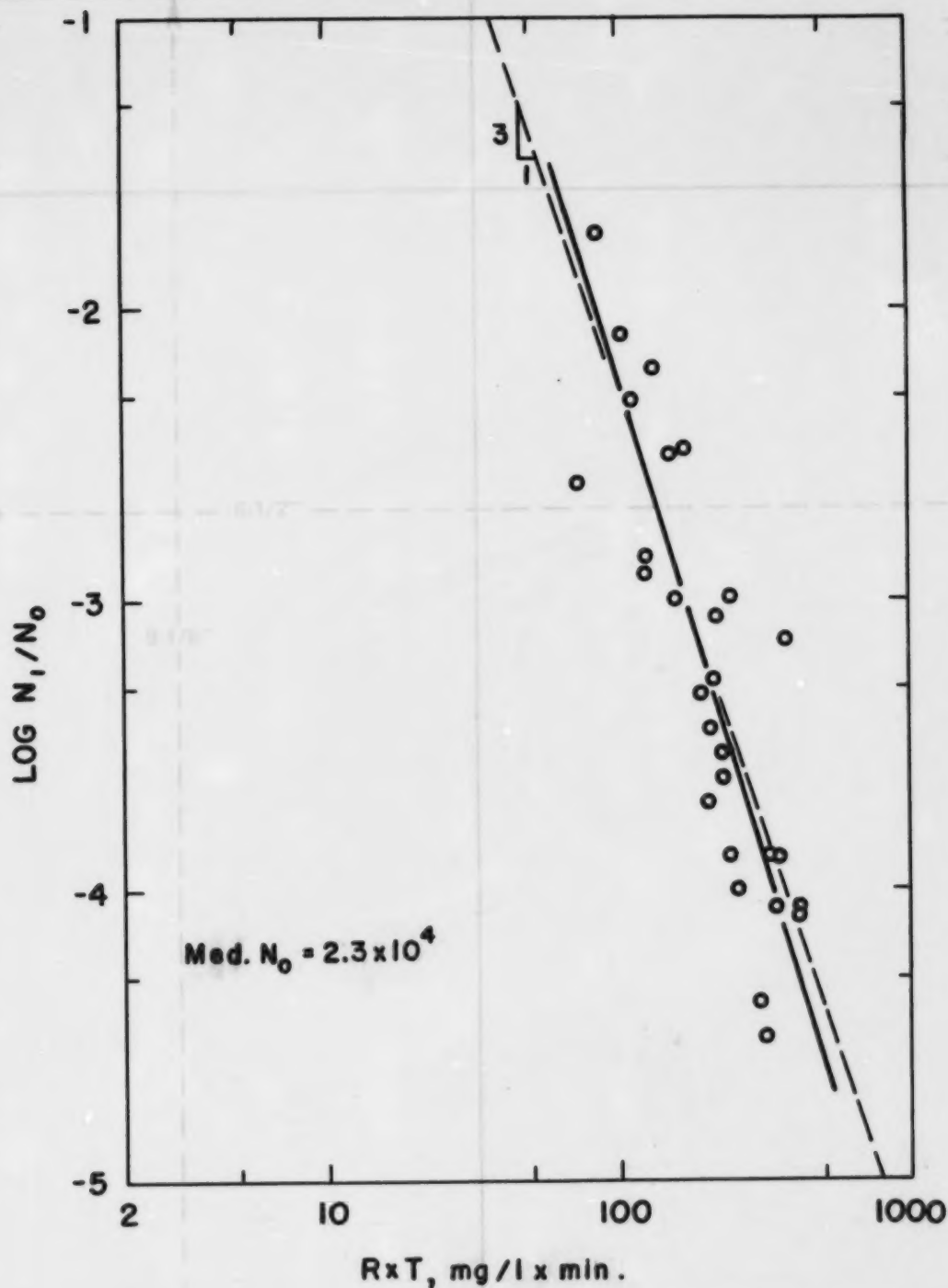


Figure 25. Coliform Bacteria Survival, Pilot Plant at Dublin-San Ramon.

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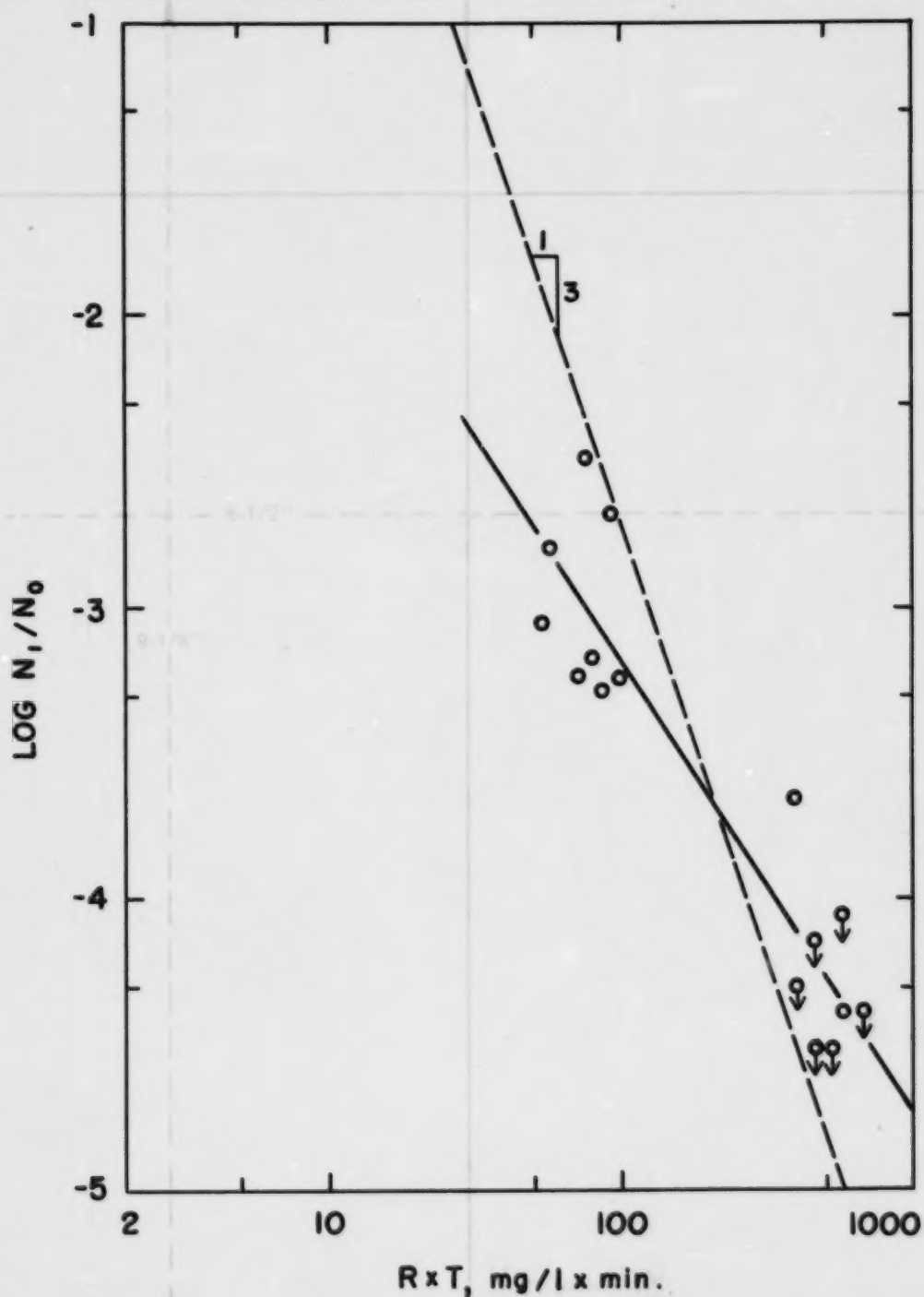
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Figure 26. Coliform Bacteria Survival, Dublin-San Ramon Plant.

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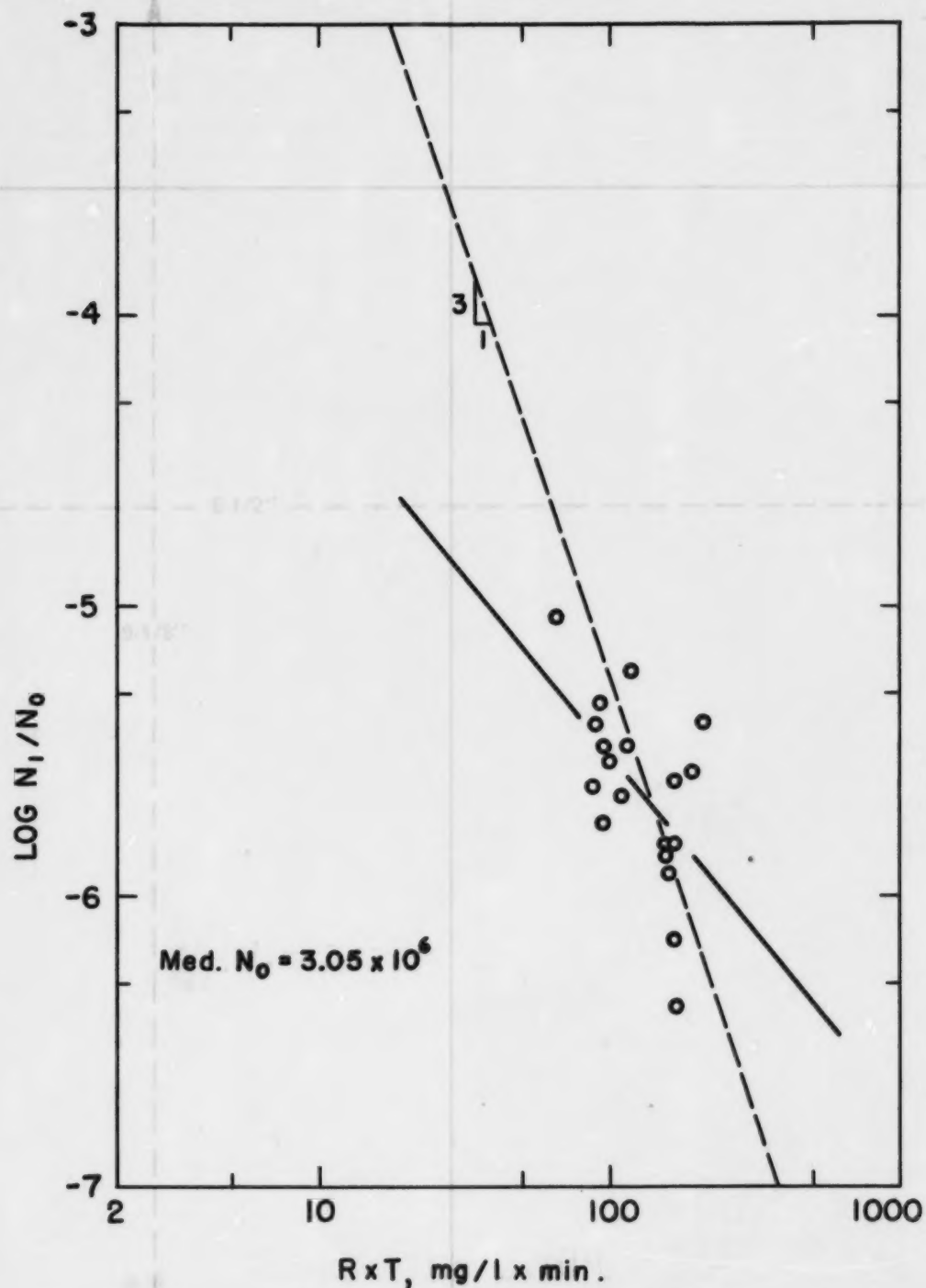


Figure 27. Coliform Bacteria Survival, Pilot Plant at Ross Valley.

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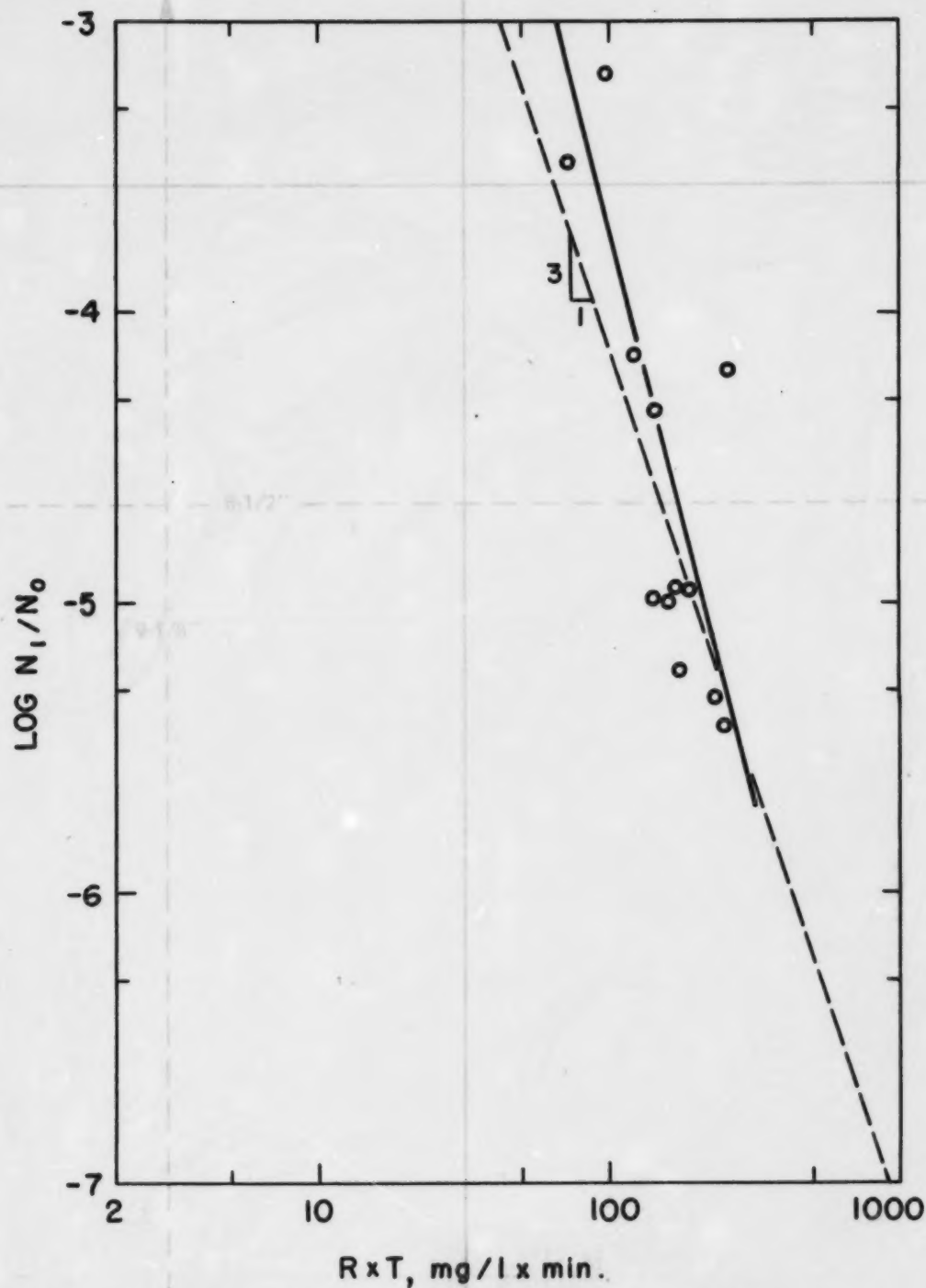


Figure 28. Coliform Bacteria Survival, Ross Valley Plant.

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nitrified effluents did not require less applied chlorine to achieve the same effect than non-nitrified effluents.

Table 6. REGRESSION ANALYSIS OF COLIFORM BACTERIA DIE-AWAY DATA^a

Treatment Plant	b	n	r	F	Level of Significance
San Leandro Plant	0.2	-1.92	0.43	1.37	0.287
Pilot Plant at San Leandro	3.7	-3.13	0.69	20.08	0.001
San Pablo Plant	4.18	-2.24	0.91	55.57	0.001
Pilot Plant at San Pablo	14.6	-4.1	0.93	127.6	0.001
Pinole Plant	0.00	-0.53	0.62	8.90	0.010
Pilot Plant at Pinole	0.3	-1.82	0.68	17.13	0.001
So. San Francisco Plant	15,000	+2.07	0.27	0.16	0.727
Pilot Plant at So. S.F.	0.1	-1.95	0.30	2.10	0.162
Sacramento CSD-N.E. Plant	0.02	-1.18	0.99	1273.	0.001
Pilot Plant at Sacramento CSD	0.1	-1.68	0.78	22.00	0.001
Roseville Plant	0.04	-1.24	0.96	163.9	0.001
Pilot Plant at Roseville	7.76	-3.50	0.81	30.56	0.001
Dublin-San Ramon Plant	0.85	-1.53	0.93	85.15	0.001
Pilot Plant at Dublin	20.7	-3.32	0.88	94.40	0.001
Ross Valley Plant	12.0	-4.04	0.72	10.84	0.008
Pilot Plant at Ross Valley	0.004	-1.24	0.55	7.67	0.013
Mean of significant values:					
Full-scale Plants	2.85	-1.8			
Pilot Plant	6.74	-2.7			

^a For the formula $N_1/N_0 = (R T/b)^n$

At Sacramento and Roseville (Figures 21 and 23, and Tables A-5 and A-6) it was observed in the pilot plant that the desired coliform level was achieved with 60 minutes contact time and that additional contact time up to two hours caused little or no lowering of the coliform level. Regression analyses of the pilot plant data were carried out for only up to 60 minutes detention time at Sacramento (Figure 21) and up to 90 minutes at Roseville (Figure 23). The indeterminate results shown on Figures 24 and 26 were counted as 2 per 100 ml in regression analysis.

Many wastewater treatment plants use their ocean outfalls as chlorine contact tanks. It was originally believed that an outfall would provide excellent coliform removal because of its good plug flow characteristics. Therefore, the project included limited studies with the long pipe contact chamber on the pilot plant which simulated an ocean outfall.

Results of the simulated outfall studies are shown in Table 7. These studies were done for one day at each site using the long 5 cm (2-inch) pipe contact chamber which provided 15 minutes contact time. The pipe had a Reynolds Number of 16,000; therefore, the flow was turbulent plug flow. At each site approximately the same control chlorine residual was used as for the baffled tank study during the preceding week. As the pilot plant wasn't designed to do concurrent studies with the two tanks, direct comparison of their performance wasn't possible. The coliform survival ratios derived from Table 7 are shown as a cross on Figures 13, 17, 19, and 23. It appears from these figures that in four out of five cases there is no significant difference in the two sets of data.

To facilitate visual comparison, the eight regression curves for the pilot plant data are depicted on Figure 29. With the exception of South San Francisco, the lowest extremity of each curve approximately indicates the point where an MPN of 2 per 100 ml was reached.

Table 7. PILOT PLANT SIMULATED OUTFALL STUDY RESULTS^a

Location	Unchlorinated Total Coliform, MPN/100 ml	After mixing		After 15 Min. Contact	
		Chlorine Residual, mg/l	Total Coliform, MPN/100 ml	Chlorine Residual, mg/l	Total Coliform, MPN/100 ml
San Leandro	79,000,000	6.5	900	6.5	560 ^b
Pinole	330,000	3.7	255,000	3.0	105
So. San Francisco	17,500,000	5.2	≥ 2,400,000	4.7	< 200
Sacramento CSD	1,350,000	2.2	295,000	1.7	305
Roseville	280,000	2.7	305,000	2.5	130

^a Median Values of 9 samples each.

^b After 7.5 minutes contact.

DEGREE OF DISINFECTION

In order to estimate the chlorine requirements of different effluents the chlorine dosage in the pilot plant was varied during one sampling week at each site. Table 8 shows the chlorine dosages and control residuals needed at each treatment plant to achieve the same effluent coliform numbers. The chlorine dosages required

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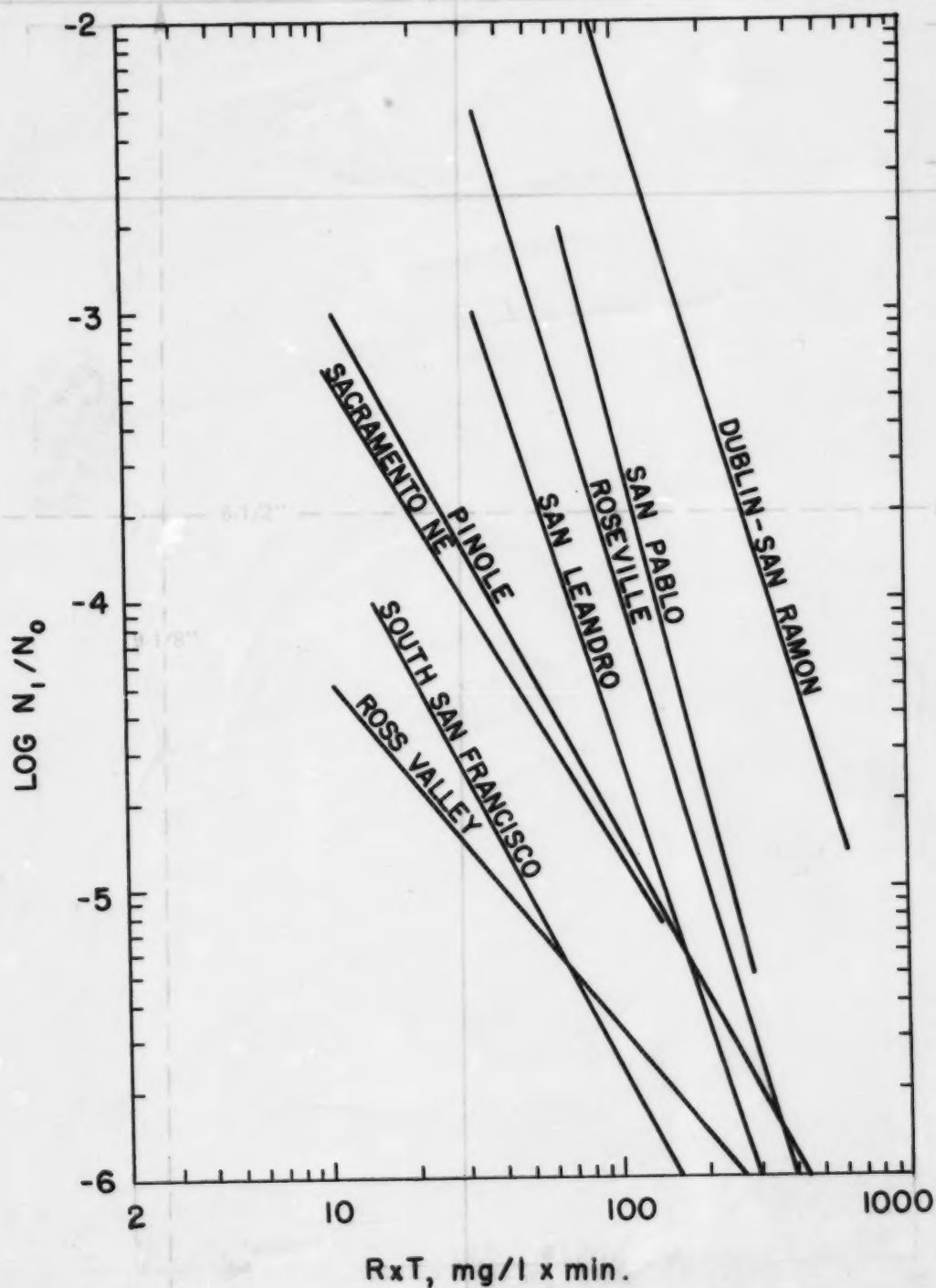


Figure 29. Regression Curves of Pilot Plant Chlorination Data .

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to achieve final coliform levels of 2 per 100 ml after 60 minutes contact time ranged from about 22 mg/l at San Leandro and Pinole to 4.1 - 7.0 mg/l at Sacramento CSD and Roseville. The chlorine residuals ranged from 11.5 mg/l at San Leandro to about 3 mg/l at Roseville.

The reasons for the high dosages at San Leandro and Pinole apparently were overall poor effluent quality and high industrial wastes content at San Leandro and probably high nitrite levels at Pinole. Both Sacramento CSD and Roseville received only domestic wastewater which may have accounted for the low dosages required.

The results at San Pablo and Dublin-San Ramon are interesting because both plants practiced complete nitrification and there were appreciable amounts of free chlorine residuals present. The Dublin-San Ramon effluent contained 80-90 percent of free residual. However, these effluents still required a chlorine dose of 12-13 mg/l to reduce the total coliform MPN to 2 per 100 ml. Since there were appreciable amounts of COD and organic nitrogen present, organo-chloramine formation could have occurred.

Table 8. PILOT PLANT CHLORINE REQUIREMENTS AT DIFFERENT LOCATIONS TO ACHIEVE THE SAME COLIFORM LEVELS

Location	Total Coliform Level, MPN/100 ml	Detention Time, Minutes	Chlorine Dosage, mg/l	Chlorine Residual, ^a mg/l
San Leandro	2	60	22.2	11.5
San Pablo	2	60	10.7 - 13.0	7.3 - 8.1
	20	60	8.6	4.3
	20	30	10.7	7.3
Pinole	2	45	16.2 - 22.8	4.8
	20	60	5.7 - 8.0	2.0 - 3.7
So. San Francisco	20	60	12.5	8.5
Sacramento CSD - N.E.	2	60	5.0 - 7.0	3.5 - 4.9
	20	30	2.6	2.0
Roseville	2	60	4.1 - 4.3	2.8 - 3.0
Dublin-San Ramon	2	60	11.5 - 12.4	10.0 - 10.9
	23	30	11.9 - 12.4	10.2 - 10.7
	230	30	7.5	4.7
Ross Valley	2	60	10.6 - 13.5	7.0 - 9.3
	20	30	5.0 - 7.5	3.0 - 3.9

^a Residual immediately after mixing, i.e. the control residual.

At Roseville the filtered effluent required a 4.1 - 4.3 mg/l chlorine dosage, whereas at Sacramento CSD the dosage was 5.0 - 7.0 mg/l. With the exception of the initial total coliform levels, the water qualities were approximately equal at both plants. The total coliform levels in the unchlorinated effluent at Roseville were an order of magnitude lower than those at Sacramento CSD.

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INITIAL MIXING STUDIES

Mixing studies were carried out on the pilot plant and at those full-scale plants where it was possible to sample immediately after mixing. The pilot plant contained two static mixers: one a 76 mm (3-inch) tee in 76 mm (3-inch) pipe, the other a 38 mm (1.5 inch) tee. The chlorine solution was injected through the tee into the flowstream through a 13 mm (1/2-inch) tube. The 76 mm (3-inch) mixer had a Reynolds Number of 38,500 and a G value of 115 sec^{-1} , whereas the 38mm (1.5 inch) mixer had a Reynolds Number of 77,000 and an estimated G value of 875 sec^{-1} . The G value is the mean velocity gradient in a shearing fluid. (5) The G value is used to estimate the energy spent on mixing the fluid; it is defined as $G = \sqrt{P/\mu}$, where P is power input per unit volume and μ is the absolute viscosity of the fluid. In addition to the tee there was a 0.76 m (30-inch) length of pipe before the sampling point of the residual analyzer was reached, and an additional length of 50 mm (2-inch) pipe to a sampling tap. A mixing length of 10 pipe diameters is believed to be adequate in tubular mixers provided that the chlorine solution is injected into the center of the flowstream (4). The total detention time in piping to this sampling tap was approximately 20 seconds.

The studies at San Leandro, San Pablo and Pinole were done with the 76 mm (3-inch) tee; the studies at Sacramento and Dublin-San Ramon were done with the 38 mm (1.5 inch) tee. At other sites the 38 mm tee was used, but no adequate data were obtained.

Results of the pilot plant mixing studies are shown on Figures 30 and 31. The data points depict the total coliform bacteria reduction in the tubular mixer after 20 seconds detention time. The reduction appears to be related to the chlorine residual, i.e., the higher the residual, the higher the percent reduction. Figure 30 shows the results with the 76 mm (3-inch) mixer which has a low G value. Although there is a wide scatter of points there is a clear trend toward higher degree of coliform kill with increasing chlorine residual. Figure 31 shows the results for the 38 mm (1.5 inch) mixer. There is much less scatter in the data points. This indicates that the 38 mm (1.5 inch) tee does a better job of mixing, apparently because it creates a higher degree of turbulence. However, the percent coliform reduction is lower in this mixer which may be due to differences in water quality.

A typical effect of mixing and contact time observed in the pilot plant is depicted on Figure 32. Immediately after initial mixing there is a rapid decline in total coliform numbers. The reason for the rapid coliform destruction during initial mixing is not known; however, it may be the presence of free chlorine or some oxidation-reduction reaction (25). This is followed by a lag time in the contact tank, and by another period of rapid decline caused by longer contact with chlorine residual. Similar lag time has been observed by others (14), but there is presently no satisfactory explanation for this phenomenon. This implies that mixing alone, or a very short contact time, is not adequate to achieve the desired coliform reduction, but that adequate contact time is also necessary.

Table 9 shows the results of initial mixing studies done on the full-scale plants. In addition to the chlorine residual and coliform results, the G value of each mixer and the mean detention time T in the mixer are shown. At Pinole, Sacramento, and Roseville the coliform samples were taken from the mixing chamber.

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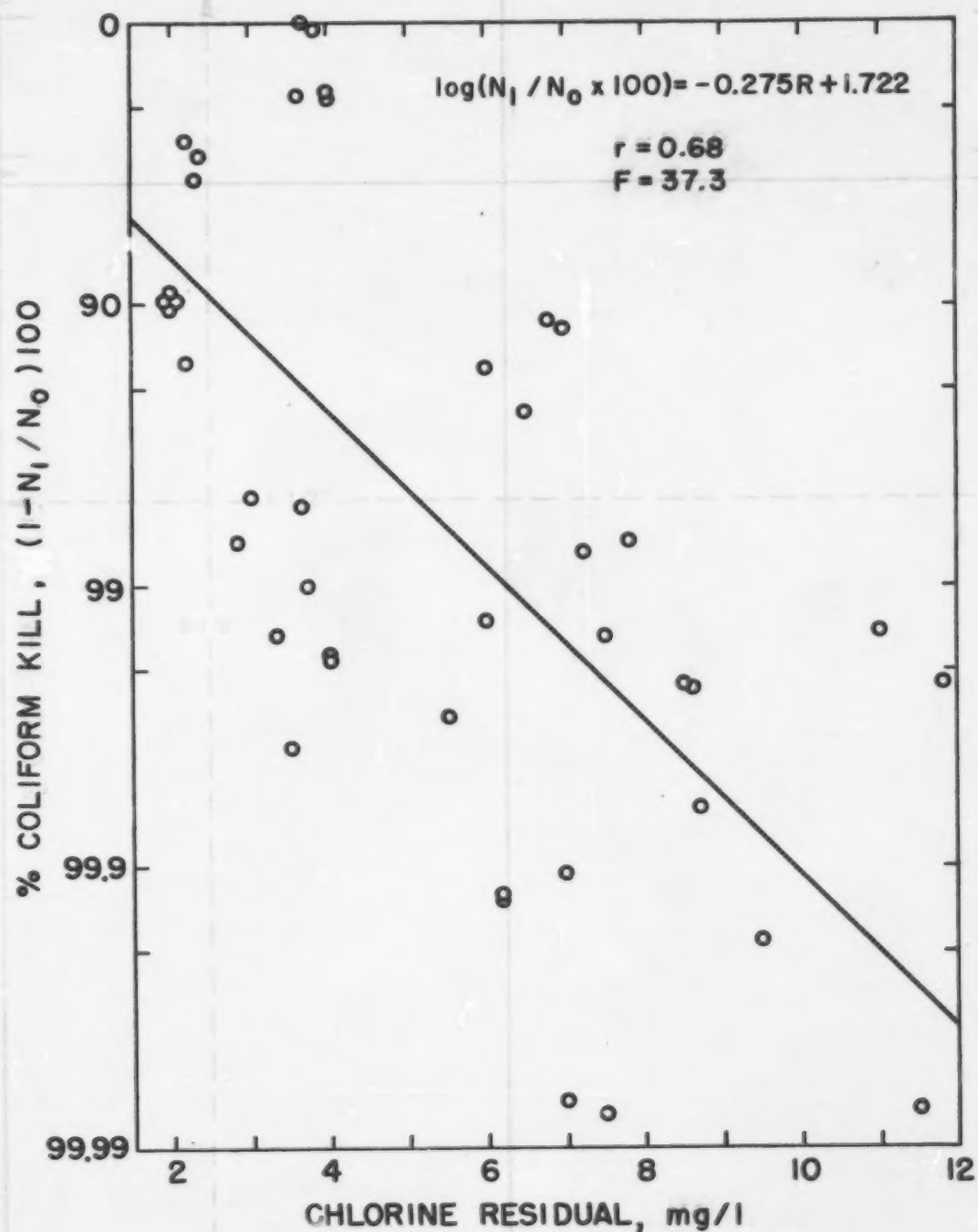


Figure 30. Coliform Kill in 76 mm Mixer as a Function of Chlorine Residual .

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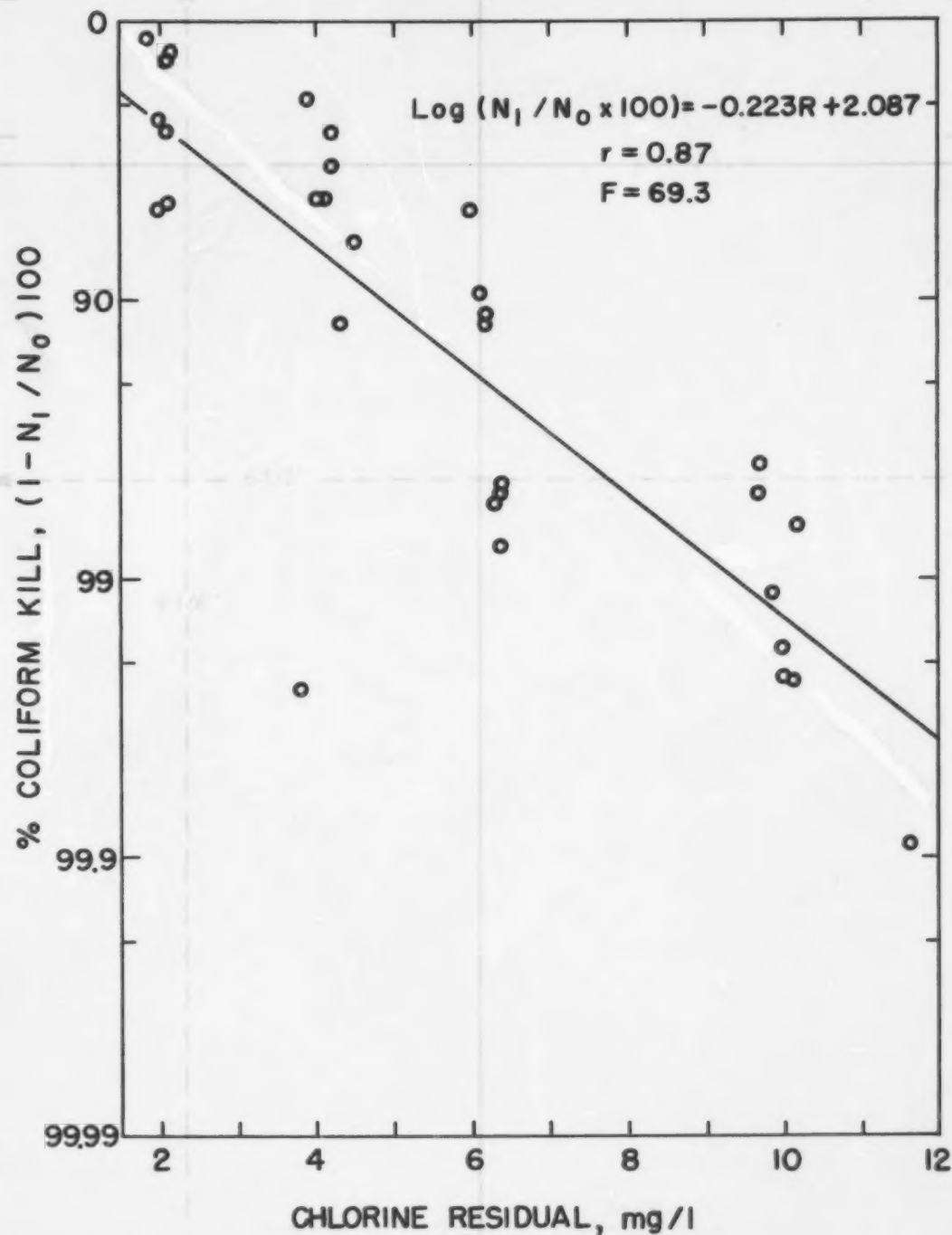
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Figure 31. Coliform Kill in 38 mm Mixer as a Function of Chlorine Residual.

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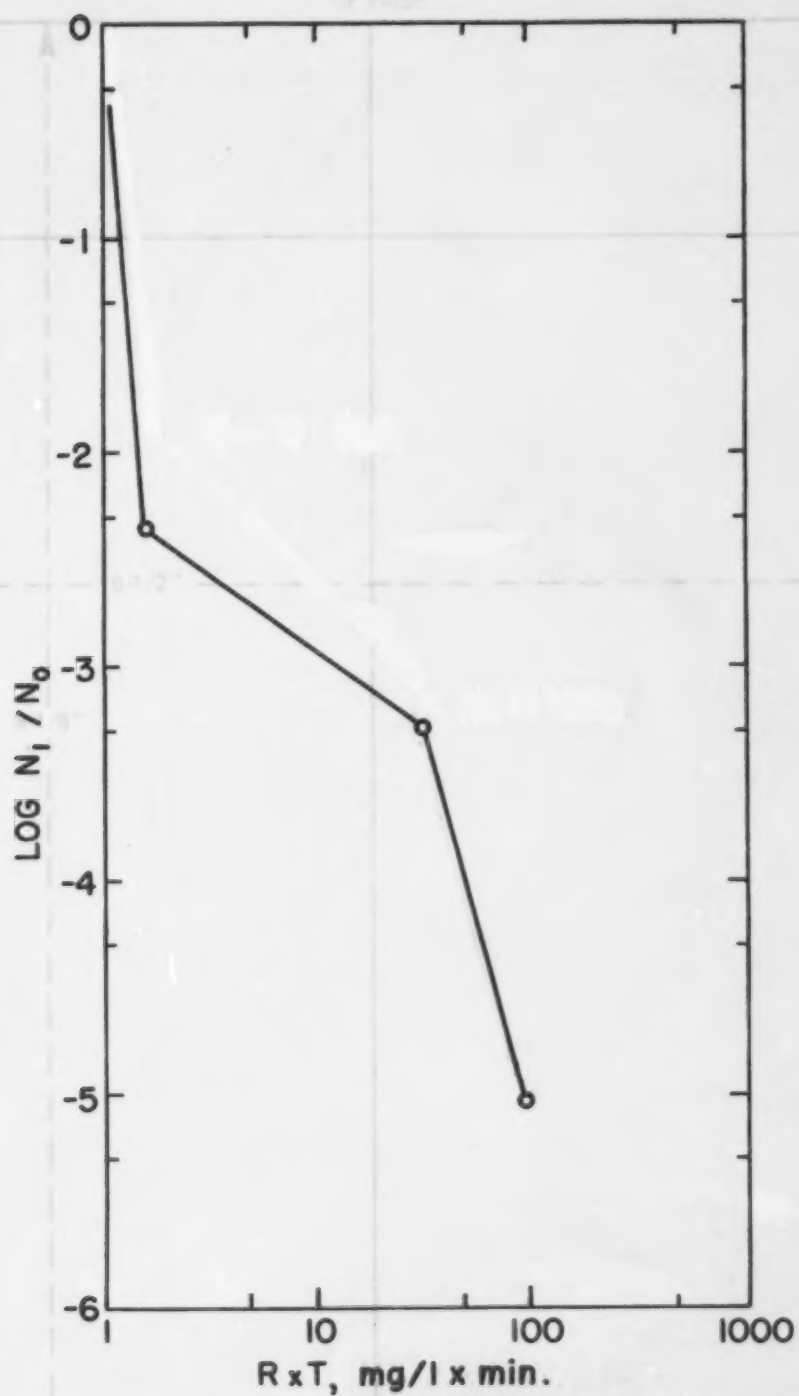


Figure 32. Typical Effect of Mixing and Contact Time on Coliform Destruction.

Table 9. RESULTS OF MIXING STUDY ON FULL-SCALE PLANTS

Location	Unchlorinated Total Coliform, MPN/100 ml ^a	TYPE	Mixer Data		Chlorinated Effluent, Chlorine Residual, mg/l	After Mixing	
			G ₁ -1 sec	T, Minutes		Total Coliform, a MPN/100 ml	Percent Reduction
Pinole	790,000	Turbine	430	2.3	6.5 ^a	280 ^b	99.96
Sacramento CSD	490,000	Turbine	850	0.2	11.6	1,200 ^b	99.7
	400,000			0.2	10.5	< 2,000 ^b	99.5
Roseville	750,000	Turbine	250	0.5	5.5	3,500 ^b	99.5
	100,000			0.4	5.9	800 ^b	99.2
Dublin-San Ramon	49,000	Turbine	530	6.0	13.8	33	99.93
	28,000			6.5	13.5	56	99.8
San Pablo	33,000	Hydraulic jump	550	13	4.0 (Est)	230	99.3
Ross Valley	3,650,000	Hydraulic jump	-	12	8.0	24,000	99.3
	3,300,000			9	7.9	1,045	99.97
	4,100,000			15	9.6	190	99.99
	2,800,000			15	17.0	177	99.99

^a Medians of 8 samples each.^b Sampled in mixing chamber.

At Dublin-San Ramon, San Pablo, and Ross Valley it was not possible to sample immediately after mixing and, while the detention time in the mixers itself was on the order of one minute, the point where samples were taken included additional contact time in the conduits following the mixer. The effect of this additional contact time is not known. At San Leandro and South San Francisco it was not possible to sample after the mixer at all.

Although there are no criteria by which to evaluate the performance of a chlorine mixer, the coliform reductions shown in Table 9 appear very good. A 99.3 percent coliform reduction appears to be achievable in all the mixers examined. There appears to be no correlation of mixer performance with the G value or detention time.

The pilot plant was always operating on a lower chlorine residual; therefore, it was not possible to directly compare the two categories of mixers. From Figures 30 and 31 it can be seen that the coliform reduction in the two pilot mixers was 90.0-97.8 percent at 5.0 mg/l chlorine residual, and 99.3-99.9 percent at 10 mg/l chlorine residual. Therefore, the performance of the pilot mixers appears to have been worse than the full-scale mixers at the lower chlorine residuals and about the same at the higher residuals. However, since the pilot mixer probably cannot be scaled up hydraulically, scaling up its performance may not be valid.

The data obtained in this study are not adequate to determine which type of mixer is the best one. However, it is quite clear that rapid mixing is very important in achieving adequate disinfection efficiency. It appears that a mixer that achieves a total coliform reduction of at least 99 percent is adequate. The turbine mixers used for chlorination are usually designed for a G value of 500-1,000 sec^{-1} , and this appears to be an appropriate range.

EVALUATION OF CHLORINE CONTROL SYSTEMS

With the exception of San Leandro and Ross Valley, all the treatment plants studied had a compound loop chlorine control system where the chlorine dosage was adjusted both by a flow signal and a residual analyzer signal. Theoretically, this is the ideal method of control, provided that it is properly designed, adjusted and operated. At the Sacramento N.E. plant the influent flow signal was used; the effluent flow signal was used at the other plants. The use of the influent flow signal is undesirable because there is a lag time of several hours from the plant influent to the chlorine contact tank. At San Leandro also, influent flow was measured but there the chlorine control was manual. At Ross Valley only flow proportional control was used; at this plant the flow rate was subject to large and rapid fluctuations due to the on and off action of the influent pumps. This adversely affected the chlorine dosage adjustment. At Dublin-San Ramon the chlorine control system was adversely affected by the drawing down of the contact tank during filter backwash which disturbed the flow pacing control. The Pinole control system was poorly adjusted and calibrated. At South San Francisco there wasn't adequate distance between the chlorine injection and the analyzer sampling points, and the system appeared to be poorly designed. The control system on the pilot plant was a well designed direct residual control where the flow rate was constant.

Table 10 shows the mean range of variations in chlorine residual for both the pilot plant and each full-scale plant observed during the daytime sampling period. It is apparent that, with the exception of San Pablo, the control provided by the pilot plant was significantly better than that of the full-scale plants. This was at least partly due to frequent cleaning and recalibration of the pilot plant equipment. Diurnal chlorine residual variations recorded by DFG (presented in Volume II of this report) are greater than those shown in Table 10; this may be partly due to diurnal changes in chlorine demand.

Table 10. MEAN RANGE OF CHLORINE RESIDUAL VARIATIONS^a

Location	Full-Scale Plant After Contact	Pilot Plant	
		Control	After Contact
San Leandro	5.5	0.8	0.4
San Pablo	0.5	0.6	0.4
Pinole	6.8	1.0	0.75
So. San Francisco	3.4	2.2	1.4
Sacramento N.E.	2.7	0.3	1.1
Roseville	0.9	0.4	0.6
Dublin-San Ramon	6.3	0.8	1.2
Ross Valley	4.4	0.2	0.4

^a Values in mg/l. Arithmetic mean range of maximum and minimum daily values.

In each case the variations in the full-scale plant data were greater than those of the pilot plant. In a well designed system the control residuals should not vary more than ± 0.5 mg/l. The plants having poor chlorine control systems also had overall poor performance as related to that of the optimized pilot plant (See Tables 3 and 4). From the above data it would appear that a poorly designed and/or operated chlorine control system may be one of the main causes for the excessive use of chlorine.

At San Leandro, which had serious sludge overflow problems, the pilot plant's residual analyzer cell clogged so fast that it wasn't possible to operate the pilot plant for more than three hours per day. At South San Francisco, which also had a sludge carryover problem, the pilot plant analyzer cell completely clogged with each sludge overflow event and had to be cleaned and recalibrated each time. In addition, the sludge depressed the chlorine residual to zero. This accounts for the large variations observed in the pilot plant's chlorine residual.

At Sacramento CSD, where the effluent contained filamentous matter, the pilot analyzer went out of calibration by about 15 percent during a 24-hour period, and had to be cleaned and recalibrated each morning. Similar problems were experienced at Roseville, although the effluent was filtered, and at Ross Valley. At most of the plants studied the sample to the analyzer was diluted with tap water whereas the pilot plant's analyzer received undiluted effluent.

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In the pilot plant's residual analyzer the buffer line tended to clog and consequently air was pulled into the line from the sight tubes. This resulted in inadequate buffer feed at night, which also could have affected calibration. During daytime this problem was corrected manually.

At nearly all plants studied the full-scale control analyzers were inadequately calibrated. In some instances this was due to inadequate maintenance and operation, in others to lack of operator training.

At Pinole, whose effluent was subject to rapid water quality changes, the pilot plant's analyzer was not able to maintain a constant chlorine residual. Each time the quality changed the control system overreacted for a period of about one hour before returning to normal.

At Roseville, the full-scale plant's chlorine dosage and control residual fluctuated over a range of ± 50 percent during filter backwash. This was due to fluctuations in the flow signal caused by the backwash cycle.

Figure 33 shows the results of static chlorine die-away tests done on the eight effluents. The tests were done by adding a chlorine dose of 15 mg/l to a liter of effluent and measuring the chlorine residual at various time intervals. Four of the effluents exhibit a relatively large chlorine demand. Of interest are the curves for San Pablo and Dublin-San Ramon effluents which exhibit large decline with increasing detention time. Both plants practice complete nitrification. The various curves depict a gradual decline of chlorine residual where the rate of decline decreases with time. In contrast the pilot plant data (included in the Appendix) exhibit a much sharper initial drop in residual at the control point (1.5 minutes detention time) followed by a slow decline with a constant rate.

Table 11 shows the decay of chlorine residual in the pilot plant's contact tank during the first 60 minutes after the initial chlorine demand has been satisfied. These values were calculated from the pilot plant data and do not appear on Figure 33. The decay is approximately 1.0 mg/l for stable effluents, and considerably higher for unstable ones. Note the very high decay in the two nitrified effluents. At San Leandro and South San Francisco the relatively high values are due to the presence of sludge.

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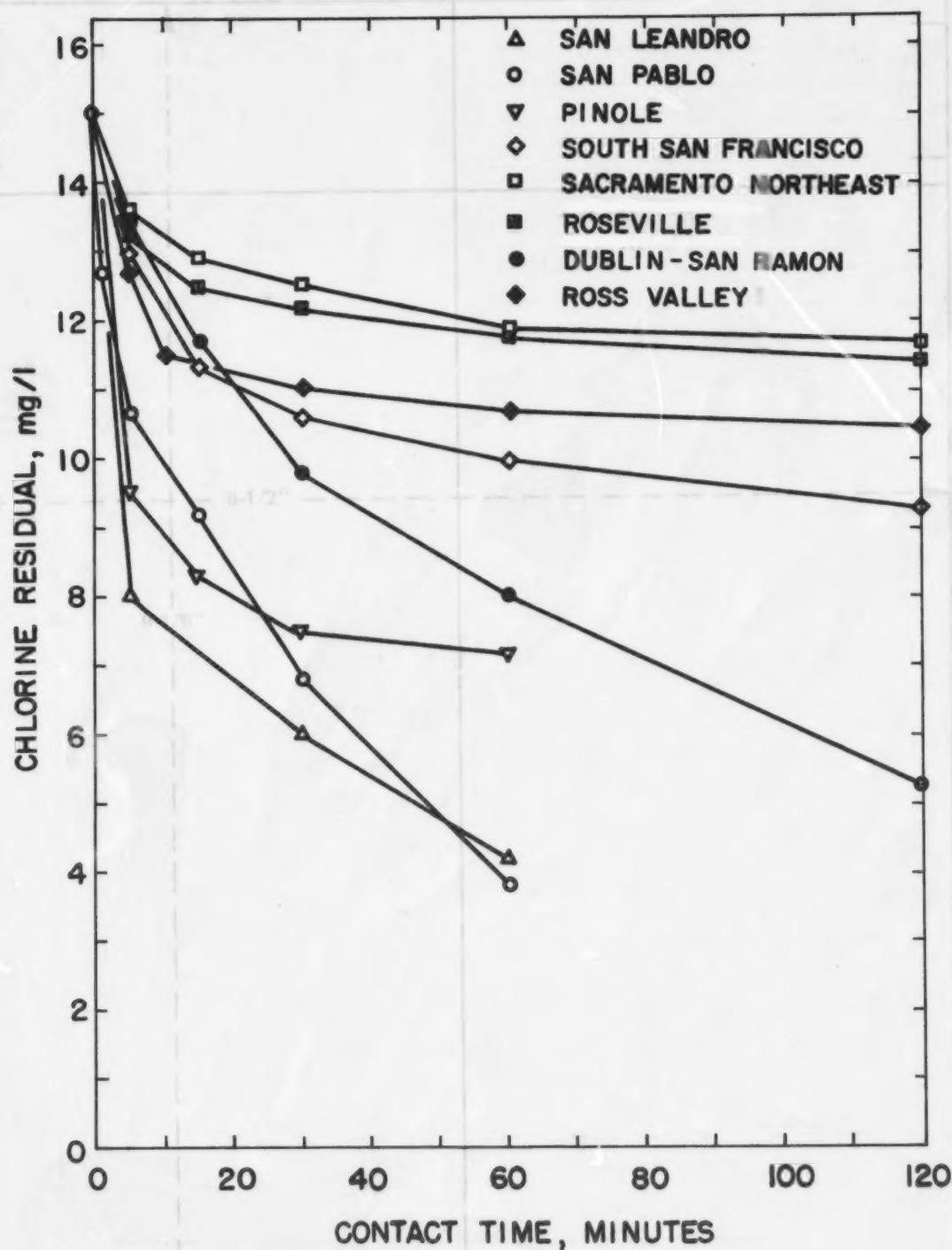


Figure 33. Chlorine Die-away Curves, Bottle Tests .

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Table 11. CHLORINE RESIDUAL DECAY IN PILOT CONTACT TANK^a

Location	Residual Decay, mg/l during 60 minutes
San Leandro	1.6
San Pablo	2.6
Pinole	1.1
South San Francisco	1.8
Sacramento CSD	1.0
Roseville	0.7
Dublin-San Ramon	4.6
Ross Valley	1.3

^aAfter satisfaction of the immediate chlorine demand; arithmetic mean values.

EFFLUENT QUALITY

Chlorine disinfection systems are often designed on the basis of the initial chlorine demand and the initial coliform density. Other quality characteristics are usually ignored because not much is known quantitatively of their effect on disinfection. Collins and Selleck (14), in studying one effluent came to the conclusion that effluent quality variations had no effect on coliform reduction. However, from Figure 29 it appears that there may be an effect. In this current study data were collected to shed light on this poorly understood subject.

The various chemical analyses which were done on each effluent are shown in Tables A-9 to A-17 in the Appendix. Temperature and pH readings are shown in Table A-18. The ranges of the major effluent quality characteristics are shown in Table 12. The daily total coliform levels are shown in Tables A-1 to A-8 in the appendix. The overall median coliform levels for each effluent are shown in Table 13.

Table 12. EFFLUENT QUALITY CHARACTERISTICS AT THE EIGHT TREATMENT PLANTS STUDIED

Plant	BOD	COD	TSS	NH ₃ -N	NO ₂ -N
San Leandro	12-29	84-109	32-140	9.3-30.8	< 0.01
San Pablo	0.7-5.2	35-82	2.4-15	< 0.1	< 0.01
Pinole	8-20	44-128	2-60	7.7-19.6	1.0-2.9
South San Francisco	16-176	39-272	12-191	26-33	< 0.01
Sacramento CSD	4.7-15.5	28-70	3-11.5	15-19	< 0.01
Roseville	2-18	18-88	4-36	5.8-14	0.02-2.2
Dublin-San Ramon	0.2-2.0	20-25	0.6-10.4	< 0.1-5	< 0.1
Ross Valley	14-26	91-132	20-49	17-27	< 0.1

Table 13. OVERALL MEDIAN INITIAL COLIFORM LEVELS, N_o , IN EACH EFFLUENT STUDIED^a

Effluent	Total Coliform MPN/100 ml
San Leandro	1.9×10^7
San Pablo	5×10^4
Pinole	1.25×10^6
South San Francisco	1.45×10^8
Sacramento N.E.	4.9×10^5
Roseville	2.8×10^5
Dublin-San Ramon	2.3×10^4
Ross Valley	3.05×10^6

^a Unchlorinated effluent, 3 weeks of sampling.

First, an attempt was made to determine whether any relationship existed between the daily variations in the initial coliform level, N_o , and those of the various chemical quality parameters. For this reason the daily values of the various quality parameters, including the chlorine demand, were graphically correlated with N_o on double log paper on a plant by plant basis. No consistent relationship was found. Table 14 shows the results of a regression analysis of BOD, and SS with N_o ; only in a few cases is there a significant correlation. In contrast, Collins and Selleck (14) had found that N_o was directly proportional to other water quality constituents.

In addition to the above, the daily variations in the chlorine dose on the pilot plant, used during the comparative study periods when the residual was held constant, was correlated with the daily values of BOD, COD and SS-volatile on a plant by plant basis. Again no significant correlation was found for any of the effluents studied. At Pinole and Roseville, both of which had high nitrite levels, the chlorine dose was correlated with nitrite-nitrogen. Figure 34 shows that at Roseville the chlorine dose increased significantly with increasing nitrite-nitrogen level. At Pinole a similar relationship was observed, but was not statistically significant. Correlation of the chlorine dose with effluent pH showed that the chlorine dose increased with increasing pH at San Leandro and San Pablo, and decreased at Pinole and Roseville. In conclusion, there was no consistent correlation of the chlorine dose with the variations in effluent quality on a plant by plant basis.

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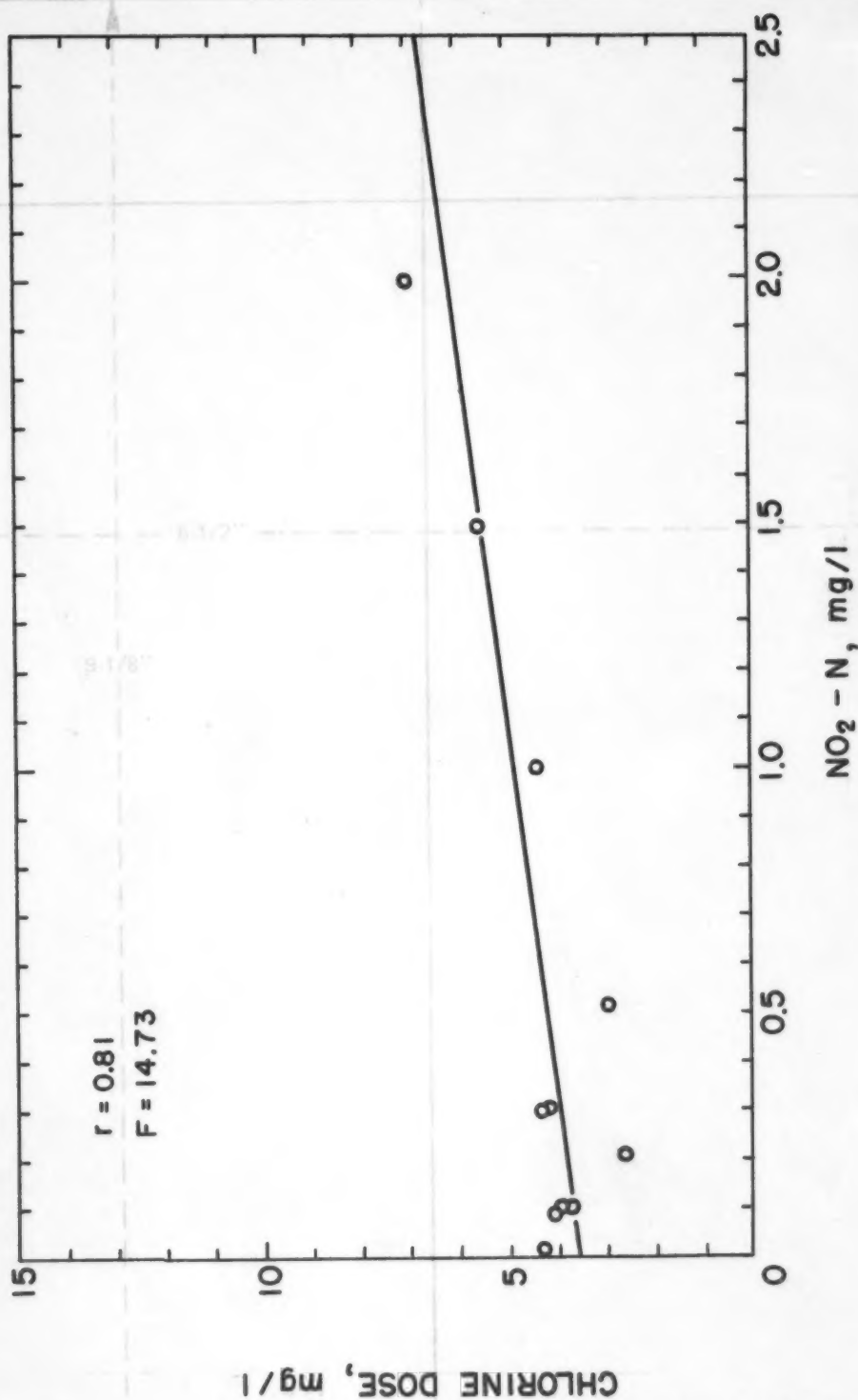


Figure 34. Effect of Nitrite on Chlorine Dose at Roseville.

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Table 14. CORRELATION OF BOD AND SS WITH INITIAL COLIFORM LEVEL^a

Treatment Plant	BOD	Correlation Coefficient "r"	
		SS-Total	SS-Volatile
San Leandro	0.87 ^b	0.24	0.07
San Pablo	0.38	0.12	0.19
Pinole	0.04	0.79 ^b	0.39
South San Francisco	0.72 ^b	0.05	0.12
Sacramento CSD-N.E.	0.42	0.52	0.31
Roseville	0.25	0.63 ^b	0.65 ^b
Dublin-San Ramon	0.12	0.12	0.49
Ross Valley	0.17	0.20	0.15

^a Using logarithms of both sets of data.

^b Statistically significant at 0.05 level.

DECHLORINATION

At all, except one, treatment plants where sulfur dioxide was used for dechlorination, the SO_2 was controlled by the feed forward control mode. This type of control uses both effluent flow pacing and a chlorine residual analyzer to control the SO_2 feed rate. The residual analyzer measures the chlorine residual at the end of chlorine contact just prior to SO_2 addition. Both the residual signal and the flow signal are combined in a multiplier and the combined signal is sent to the sulfonator orifice positioner. Periodically for about 5 minutes per hour the sample to the analyzer is switched over to a point downstream from the SO_2 diffuser to monitor the dechlorinated effluent. Usually the SO_2 is dosed to a slight excess to make sure of complete dechlorination.

At Ross valley, the SO_2 dose was controlled by flow pacing only.

The SO_2 diffuser at the plants studied was located either at the chlorine contact tank effluent weir, in a Parshall flume, or in the effluent pipe. In each case, there was adequate turbulent mixing at the point of SO_2 addition. Since the SO_2 reacts very rapidly with the chlorine residual, no additional contact time was necessary.

Acute 96-hr. fish bioassays done at three plants indicated that sulfur dioxide removed all chlorine induced toxicity from the effluents. The excess sulfur dioxide residual itself apparently was not toxic to test fish. These results are discussed in detail in Volume II of this report (21).

The pilot plant effluents contained an average of 3.3 mg/l less chlorine residual than the full-scale effluents. Since the practical ratio of sulfur dioxide to that of chlorine is 1:1 by weight this implies significant savings in sulfur dioxide used in dechlorination.

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OPTIMUM ECONOMIC CONTACT TIME

One of the principal objectives of the design of the chlorination-dechlorination system is to produce adequately disinfected effluent at minimum cost. Using Equation 1 and simple economic analysis, a differential equation for partial cost of chlorination can be written from which the most cost effective contact time can be calculated. The symbols used herein are as follows:

CRF = Capital Recovery Factor

N_0 = Average (median or geometric mean) concentration of coliform bacteria immediately prior to chlorination

N_1 = Average concentration of coliforms permitted in the effluent

$S = N_1/N_0$ = Required bacterial reduction

T = Mean residence time in chlorine contact chamber, minutes

C_c = Unit cost of chlorine, \$/kg

C_s = Unit cost of SO_2 , \$/kg

C_t = Unit cost of chlorine contact chamber, \$/m³ chamber volume

D = Total chlorine demand, mg/l

R = Chlorine residual after contact, mg/l

$CE = DE$ = Cost of chlorination or dechlorination equipment, respectively

Q = Mean effluent flow, m³/d.

The annual cost of chlorine is

$$365 Q(10^{-3})(R+D) C_c = 0.365 Q(R+D)C_c$$

and the annual cost of SO_2 dechlorinating agent is

$$365 Q(10^{-3})(R)C_s = 0.365 Q(R)C_s$$

where the ratio of 1.0 is used instead of the stoichiometric ratio of 0.90 to permit a safety factor in achieving complete dechlorination. The total cost of the chlorine contact chamber is

$$1/(24 \times 60) Q \times T \times C_t = 6.94 \times 10^{-4} Q \times T \times C_t$$

and all other equipment and labor costs are assumed independent of T .

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The total partial annual cost is then calculated as follows:

$$\text{Total Partial Cost} = \text{CRF} (6.94 \times 10^{-4} \text{ QTC}_t + \text{CE} + \text{DE}) + 0.365 \text{Q} [(R+D)\text{C}_c + (R)\text{C}_s] \quad (2)$$

where CE and DE are dependent on Q but not on T.

In the above Equation (2) it is assumed that sizing of the dechlorination facility does not depend on sizing of the chlorine contact chamber. Also assumed is that no contact chamber is needed for SO_2 dechlorination. Labor and maintenance costs were left out because it was assumed that they would be independent of detention time and would cancel out.

The relationship between R and T is established from Equation (1) (see Section 2) for a properly designed contact chamber as follows:

$$R = b S^{1/n} / T \quad (3)$$

The optimum residence time T is obtained by substituting Equation (3) into Equation (2), differentiating with respect to T, and setting the result to zero, or

$$\frac{d(\text{Total Cost})}{dT} = \text{CRF} \times \text{C}_t - 526 b S^{1/n} T^{-2} (\text{C}_c + \text{C}_s) = 0 \quad (4)$$

$$\text{and optimum } T = 22.9 [b S^{1/n} (\text{C}_c + \text{C}_s) / \text{CRF} \times \text{C}_t]^{1/2} \quad (5)$$

The use of Equation (5) can be illustrated by the following example:
Assume CRF = 0.09439 at 7% interest for 20-year life; CE = \$60,000 for a 37,850 m^3/d (10 mgd) plant; cost of chlorine \$0.24/kg (\$0.11/lb); cost of sulfur dioxide \$0.29/kg (\$0.13/lb); cost of chlorine contact chamber \$92.4/ m^3 (\$0.35/gallon). Assume also that $N_0 = 2.4 \times 10^6$ MPN/100 ml; $N_1 = 240$ MPN/100 ml; $D = 5.0$ mg/l; $S = 1 \times 10^{-4}$. From Table 6, $b = 6.74$ mg/l minutes and $n = -3$ (approximately).

Then, for an optimized system

$$\begin{aligned} \text{optimum } T &= 22.9 [6.74 (10^{-4})^{-1/3} (0.24 + 0.29) / 0.09439 \times 92.4]^{1/2} \\ &= 68 \text{ minutes} \end{aligned}$$

Equation (5) can be used for preliminary estimation of the size of a plug flow type contact tank needed. The average initial coliform level, N_0 , and the chlorine demand, D, for a particular effluent should be determined by laboratory tests. Other, more elaborate methods for determining optimum contact time for given wastewater quality and disinfection requirement are outlined by White (5). It should be noted, however, that the germicidal efficiency of the chlorine residual decreases with time which may impose a practical limit on the contact time. More research would be welcome in this area.

MULTIPLE TUBE-MEMBRANE FILTER COMPARISON STUDY

Every fifth chlorinated sample was analyzed for total coliform both by the membrane filter (MF) procedure and the multiple tube MPN procedure. The membrane filter results, in Number/100 ml, were plotted against the corresponding multiple tube (MT) results in MPN/100 ml, on Figures 35 to 42. The dashed line is the theoretical line of best fit, whereas the solid line is the actual line of best fit as determined by least squares regression analysis. As can be seen from the Figures, there is very poor correlation between the two sets of data. Table 15 shows the correlation coefficients of the regression curves. The results for San Pablo, Sacramento CSD and Ross Valley are not statistically significant.

Table 15. REGRESSION ANALYSIS OF MT VS MF DATA^a

Treatment Plant	r	F	Level of Significance
San Leandro	0.67	34.63	0.001
San Pablo	0.25	2.86	0.098
Pinole	0.51	15.96	0.001
So. San Francisco	0.39	5.05	0.032
Sacramento CSD-N.E.	0.09	0.32	0.577
Roseville	0.93	226.64	0.001
Dublin-San Ramon	0.78	47.59	0.001
Ross Valley	0.27	2.31	0.139

^a Using logarithms of both sets.

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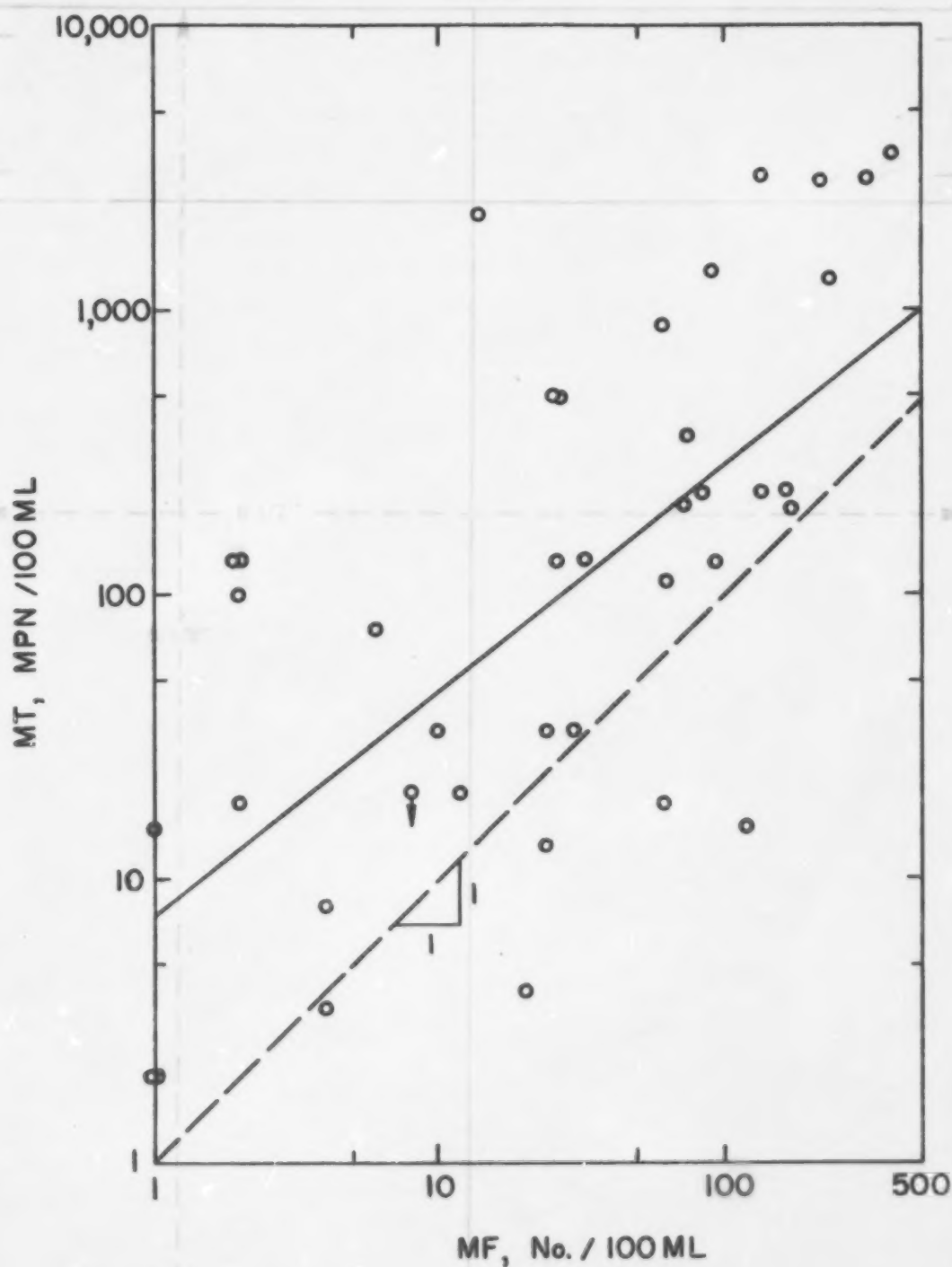


Figure 35. MT / MF Comparison, San Leandro .

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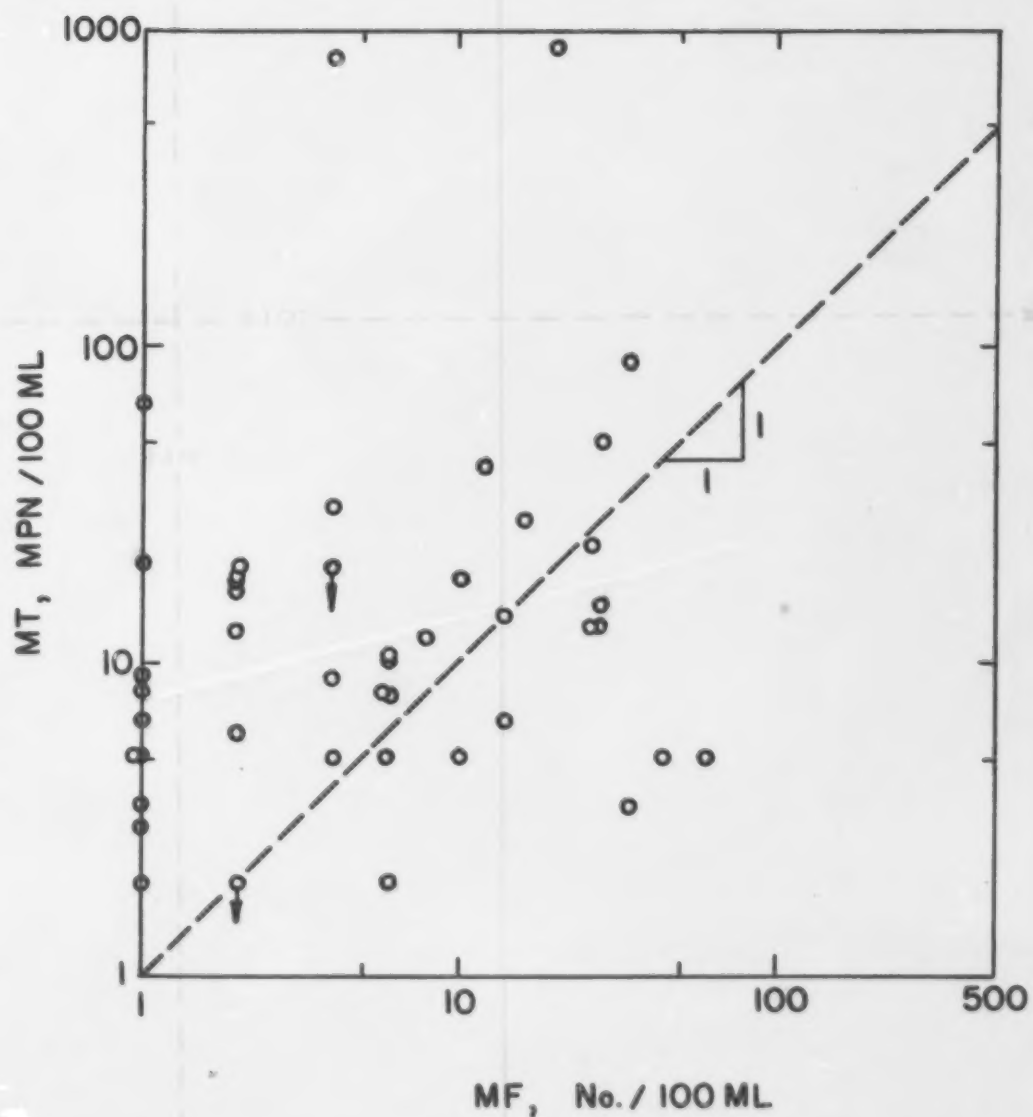


Figure 36. MT/MF Comparison, San Pablo.

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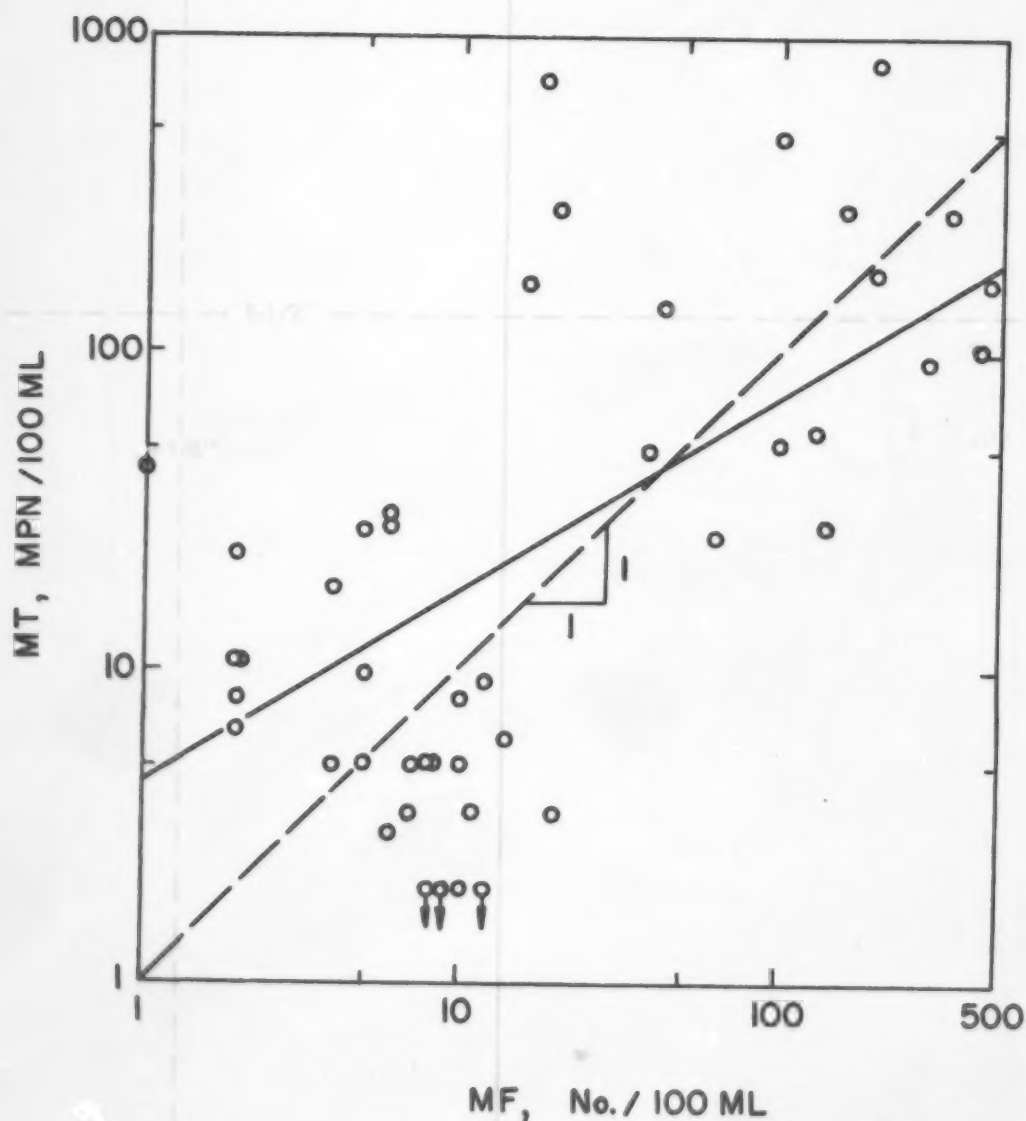


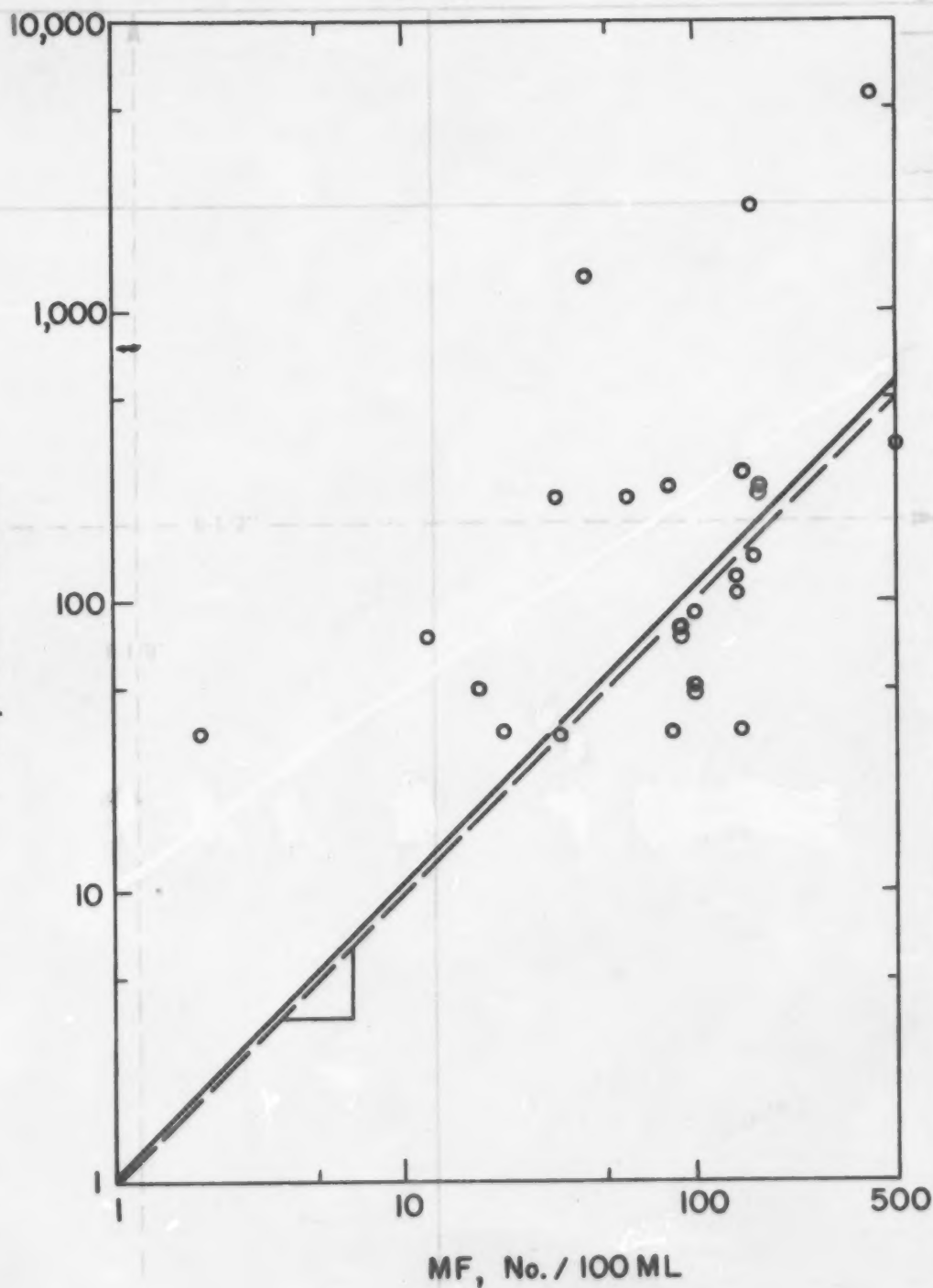
Figure 37. MT/MF Comparison, Plinole.

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Figure 38. MT/MF Comparison, South San Francisco.

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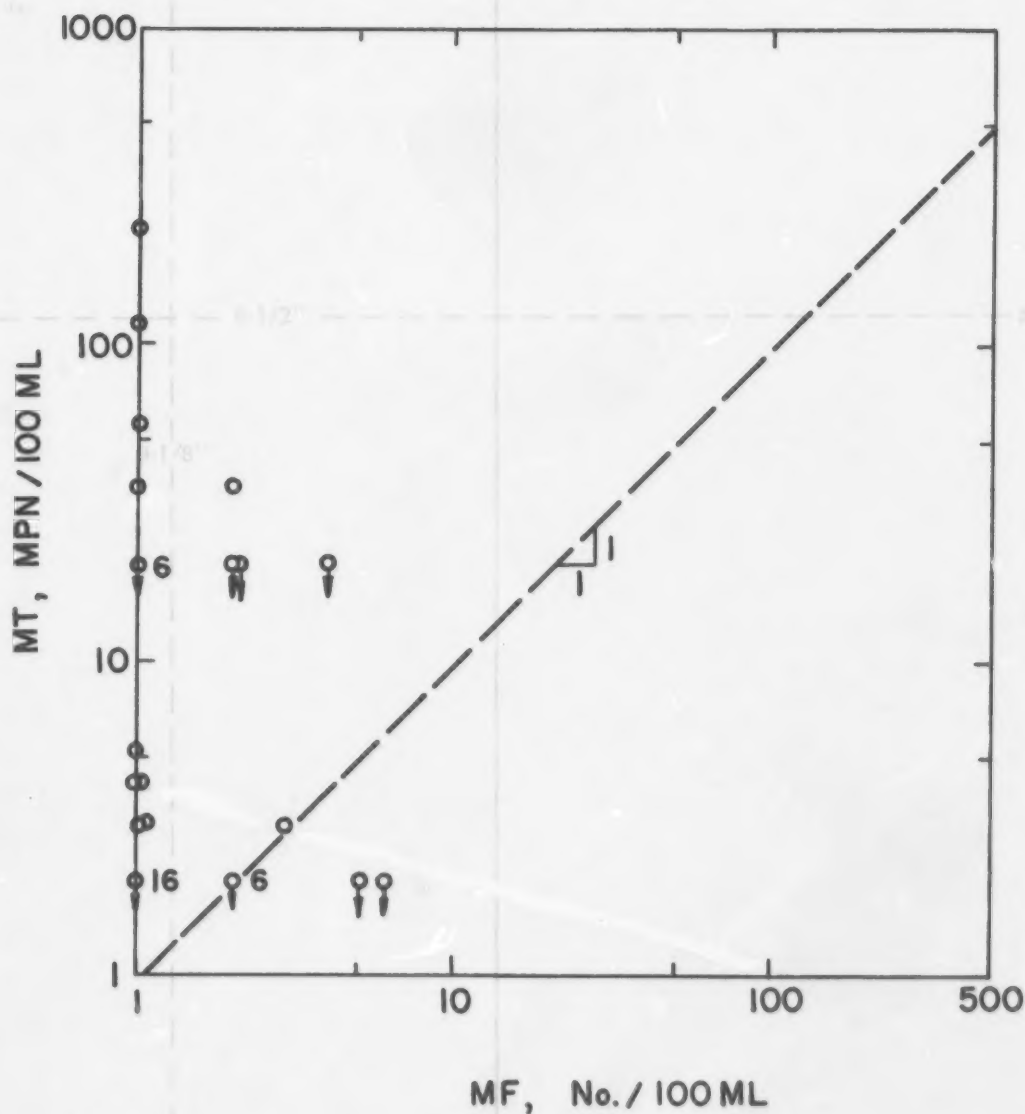


Figure 39. MT/MF Comparison, Sacramento CSD.

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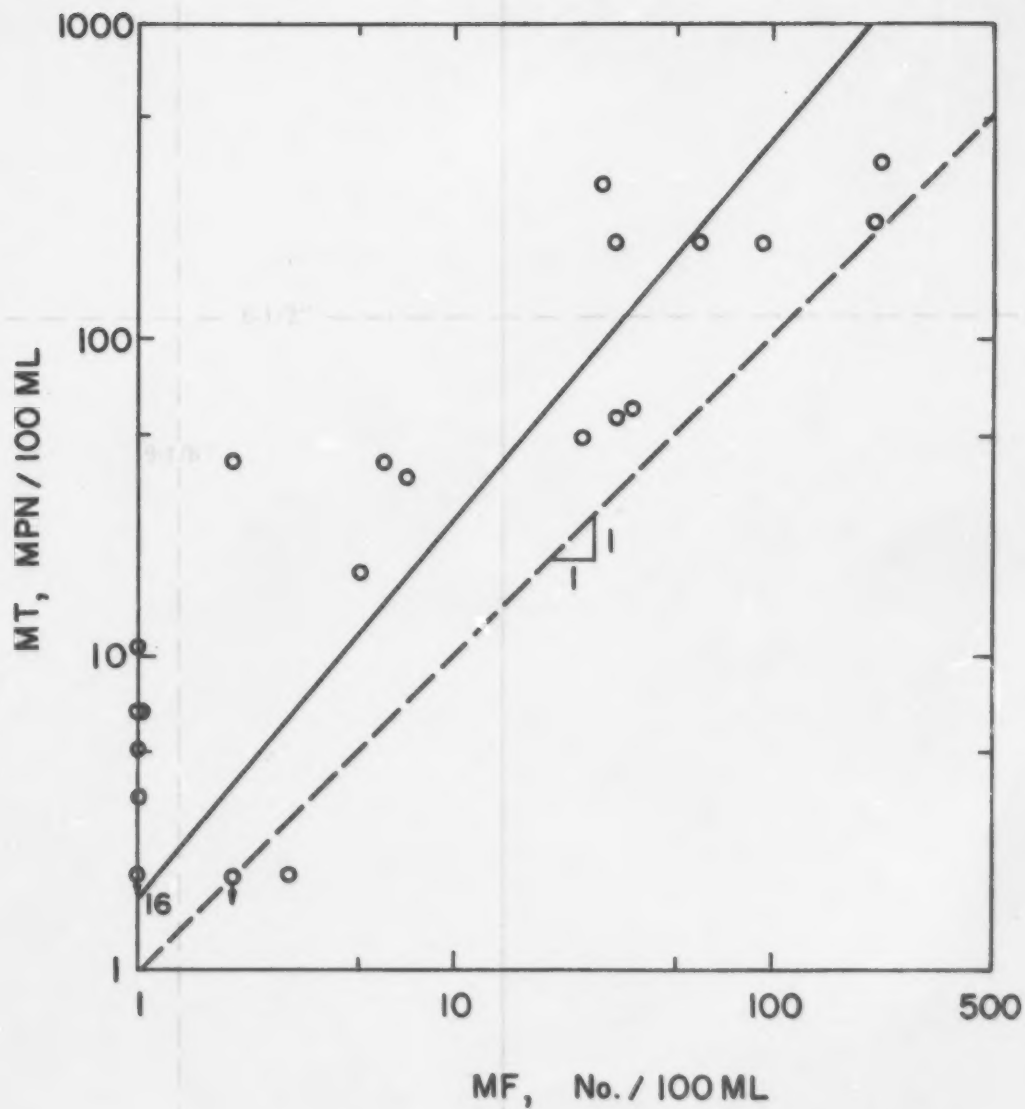


Figure 40. MT/MF Comparison, Roseville.

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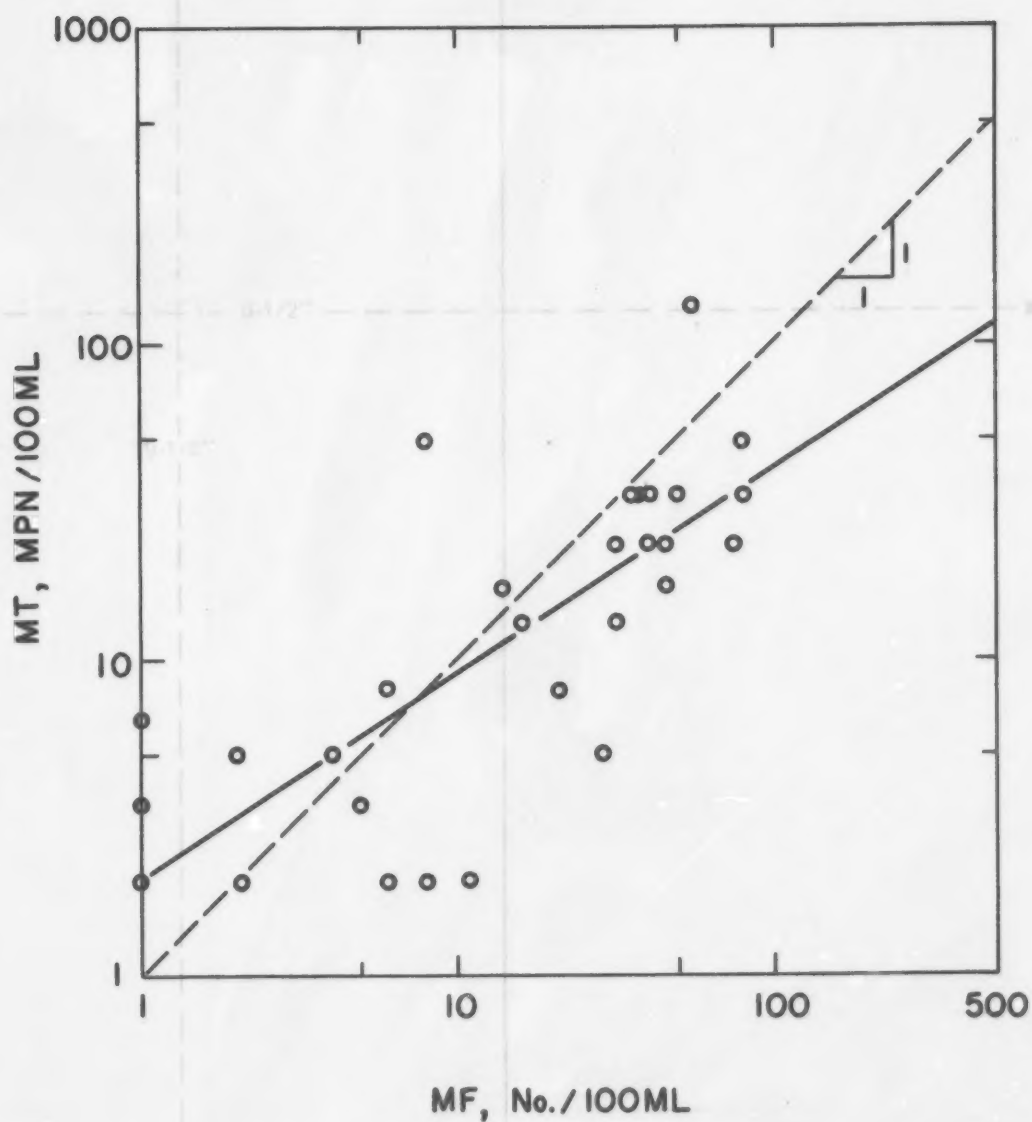


Figure 41. MT/MF Comparison, Dublin-San Ramon.

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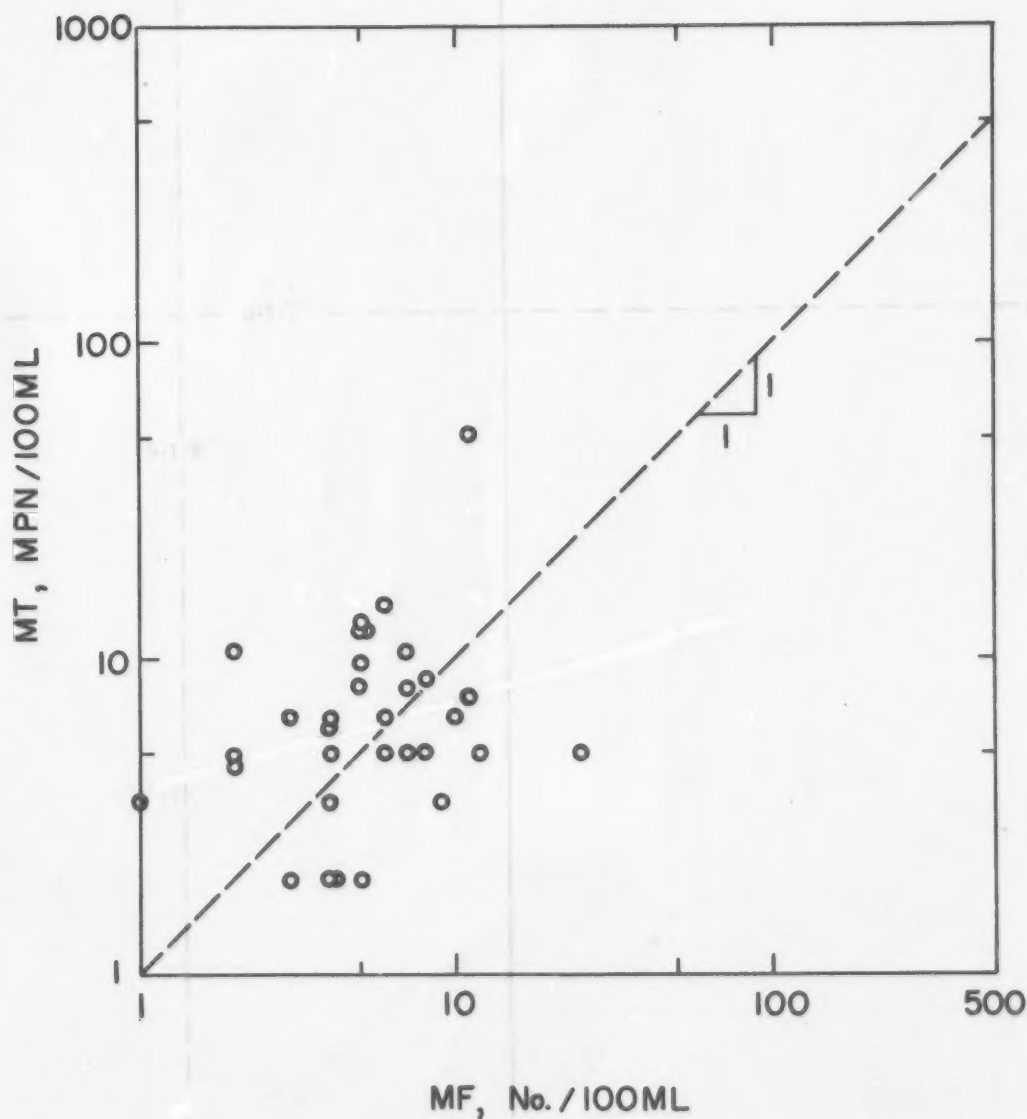


Figure 42. MT / MF Comparison, Ross Valley .

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SECTION 6

APPENDIX

BASIC DATA ON CHLORINATION

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Table A-1 CHLORINATION RESULTS TREATMENT PLANT: San Leandro

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling	Station #1:	Unchlorinated effluent								
2-14-78								13,000,000	3,100,000	6,400,000
2-15-78								24,000,000	1,300,000	4,100,000
2-16-78								54,000,000	11,000,000	13,500,000
2-17-78								54,000,000	4,900,000	35,000,000
2-21-78								240,000,000	3,300,000	13,000,000
2-22-78								23,000,000	1,300,000	14,000,000
2-23-78								170,000,000	33,000,000	64,000,000
2-24-78								240,000,000	23,000,000	64,000,000
2-27-78								23,000,000	7,900,000	15,000,000
2-28-78								79,000,000	23,000,000	41,000,000
3-01-78								350,000,000	17,000,000	49,000,000
3-02-78								130,000,000	11,000,000	23,000,000
Sampling	Station #2:	Chlorinated effluent after contact								
2-14-78	49	12.0	12.0	12.0	9.7	8.0	8.9	23	2	11
2-15-78	47	12.0	12.0	12.0	13.7	1.5	8.6	2,400	< 2	2
2-16-78	50	14.0	12.0	13.0	14.3	9.4	10.7	2,400	< 2	6
2-17-78	49	12.0	12.0	12.0	14.0	6.8	7.8	13	< 2	4
2-27-78	56	12.0	12.0	12.0	9.1	5.5	6.4	70	< 2	18
2-28-78	56	12.0	12.0	12.0	11.2	5.0	5.9	130	2	36
3-01-78	53	11.2	10.6	11.1	11.1	5.2	6.0	490	5	20
3-02-78	47	12.0	9.8	10.9	8.0	5.8	6.2	140	33	79
^a Median value, theoretical detention including 10 minutes in sample line										

Table A-1

CHLORINATION RESULTS (Cont.) TREATMENT PLANT: San Leandro

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #3		B: Pilot plant after mixing								
2-14-78		13.4	13.2	13.3	8.5	6.0	7.3	24,000	24,000	24,000
2-15-78		11.5	11.5	11.5	7.2	7.1	7.1	350,000	33,000	109,500
2-16-78		11.2	11.2	11.2	6.8	6.5	6.6	1,600,000	540,000	1,600,000
2-17-78		13.2	11.8	12.5	7.5	7.0	7.3	220,000	2	43,450
2-21-78		22.4	22.4	22.4	11.7	11.2	11.5	13,000	< 20	2,490
2-22-78		22.1	21.8	22.0	11.7	11.5	11.6	24,000	490	4,100
2-23-78		9.8	9.5	9.6	6.0	5.0	5.5	>2,400,000	< 200	>1,200,000
2-24-78		21.8	9.8	21.8	6.2	1.0	5.5	> 240,000	130	> 122,000
2-27-78		11.8	11.8	11.8	6.7	6.7	6.7			
2-28-78		10.9	10.9	10.9	5.7	5.3	5.5			
3-01-78		10.0	9.5	9.8	5.6	5.0	5.3			
3-02-78		9.5	8.7	9.1	5.3	4.8	5.1			
Sampling Station #4		A: Pilot plant, 30 minutes contact								
2-21-78	30	22.4	22.4	22.4				20	< 20	< 20
2-22-78	30	22.1	21.8	22.0				< 20	< 20	< 20
2-23-78	30	9.8	9.5	9.6				80	< 20	< 20
2-24-78	30	21.8	21.8	21.8				130	< 20	130
2-27-78	30	11.8	11.8	11.8	5.7	5.6	5.7	130	2	33
2-28-78	30	10.9	10.9	10.9	5.0	4.6	4.8	230	33	120
3-01-78	30	10.0	9.5	9.8	4.8	4.3	4.6	700	130	230
3-02-78	30	9.5	8.7	9.1	4.7	4.3	4.5	3,500	49	330

Table A-1 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: San Leandro

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4		B: Pilot plant			60 minutes contact					
2-21-78	60	22.4	22.4	22.4	9.7	9.6	9.6	33	< 2	2
2-22-78	60	22.1	21.8	22.0	10.0	9.8	9.9	5	< 2	< 2
2-23-78	60	9.8	9.5	9.6	5.0	3.8	4.4	170	8	56
2-24-78	60	21.8	21.8	21.8	3.0	3.0	3.0	49	5	15
2-27-78	60	11.8	11.8	11.8	5.3	5.3	5.3	23	< 2	10
2-28-78	60	10.9	10.9	10.9	3.8	3.8	3.8	130	33	49
3-01-78	60	10.0	9.5	9.8				170	33	79
3-02-78	60	9.5	8.7	9.1				330	31	225
Sampling Station #4		E: Pilot plant,			15 minutes contact					
2-14-78	15	13.2	13.2	13.2				3,500	330	2,300
2-15-78	15	11.5	11.5	11.5				3,500	2,400	3,500
2-16-78	15	11.2	11.2	11.2				24,000	2,400	6,350
2-17-78	15	11.5	10.4	11.0				3,500	490	1,045
Sampling Station #4		F: Pilot plant			45 minutes contact					
2-14-78	45	13.2	13.2	13.0	6.5	6.5	6.5	70	7	22
2-15-78	45	11.5	11.5	11.5	6.5	6.0	6.3	49	4	33
2-16-78	45	11.2	11.2	11.2	6.2	5.8	6.0	490	22	132
2-17-78	45	11.5	10.4	11.0	6.5	5.7	6.1	49	17	28

CHLORINATION RESULTS

TREATMENT PLANT: San Pablo

Table A-2

Date	Detention, Minutes ^a	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #1:		Unchlorinated effluent								
4-10-78								140,000	33,000	33,000
4-11-78								130,000	23,000	49,000
4-12-78								70,000	23,000	33,000
4-13-78								79,000	23,000	41,000
4-17-78								1,600,000	33,000	295,000
4-18-78								1,300,000	80,000	230,000
4-19-78								130,000	70,000	80,000
4-20-78								80,000	< 20,000	50,000
4-24-78								80,000	20,000	50,000
4-25-78								90,000	20,000	65,000
4-26-78								170,000	20,000	75,000
Sampling Station #2:		Chlorinated effluent after contact								
4-10-78	73	12.0	9.2	9.7	1.7	1.3	1.5	1,300	< 2	18
4-11-78	73	11.1	8.6	9.2	1.6	1.0	1.2	130	13	20
4-12-78	78	12.6	10.0	10.6	1.8	0.8	1.8	490	5	15
4-13-78	73	10.4	9.3	9.6	1.8	1.0	1.3	230	23	64
4-24-78	77	10.6	10.0	10.5	2.5	2.3	2.5	79	5	< 20
4-25-78	73	11.4	9.6	10.4	2.0	1.8	1.9	130	5	23
4-26-78	70	11.0	9.5	10.2	2.5	1.9	1.9	17	5	13
^a Median value, theoretical detention										

Table A-2 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: San Pablo

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #2 A: Chlorinated effluent										
4-10-78	13	12.0	9.2	9.7	6.0	4.0	4.0	2,400	33	230
Sampling Station #3 B: Pilot plant after mixing										
4-10-78		8.3	8.0	8.0	4.3	3.8	4.0			
4-11-78		8.3	8.0	8.0	4.5	4.0	4.0			
4-12-78		8.9	8.3	8.6	4.6	4.3	4.6			
4-13-78		9.1	8.6	8.6	4.8	4.2	4.3			
4-17-78		11.1	10.0	10.7	8.6	6.2	7.3			
4-18-78		15.2	11.1	13.3	9.5	7.0	8.1	350,000	790	2,400
4-19-78		8.0	6.6	7.0	4.0	3.5	3.6	790	< 20	140
4-20-78		8.0	6.7	8.0	4.0	2.8	3.2	2,300	130	640
4-24-78		8.3	7.8	7.9	5.0	4.5	4.8	1,100	230	330
4-25-78		8.9	8.3	8.8	5.5	4.0	4.5			
4-26-78		8.6	7.8	8.5	4.6	4.4	4.5			

Table A-2 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: San Pablo

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4 A: Pilot plant, 30 minutes contact										
4-10-78	30	8.3	8.0	8.0				79	< 2	13
4-11-78	30	8.3	8.0	8.0				79	13	33
4-12-78	30	8.9	8.3	8.6				79	13	13
4-13-78	30	9.1	8.6	8.6				140	33	49
4-17-78	30	11.9	10.0	10.7				49	2	11
4-18-78	30	15.2	11.1	13.3				8	< 2	5
4-19-78	30	8.0	6.6	7.0				230	33	112
4-20-78	30	8.0	6.7	8.0				230	< 20	80
4-24-78	30	8.3	7.8	7.9				79	2	15
4-25-78	30	8.9	8.3	8.8				49	17	8
4-26-78	30	8.6	7.8	8.5				170	13	8
Sampling Station #4 B: Pilot plant, 60 minutes contact										
4-10-78	60	8.3	8.0	8.0	1.5	1.5	1.5	33	< 2	8
4-11-78	60	8.3	8.0	8.0	2.0	1.7	1.8	13	5	13
4-12-78	60	8.9	8.3	8.6	1.8	0.8	1.8	23	2	7
4-13-78	60	9.1	8.6	8.6	2.0	1.7	1.7	49	5	20
4-17-78	60	11.9	10.0	10.7	6.0	3.0	4.0	8	< 2	2
4-18-78	60	15.2	11.1	13.3	4.8	4.0	4.3	8	< 2	2
4-19-78	60	8.0	6.6	7.0	3.0	1.6	1.8	1,700	5	41
4-20-78	60	8.0	6.7	8.0	1.6	0.8	1.5	130	<20	20
4-24-78	60	8.3	7.8	7.9	2.5	2.1	2.4	130	< 2	15
4-25-78	60	8.9	8.3	8.8	2.1	1.6	1.9	23	5	8
4-26-78	60	8.6	7.8	8.5	2.3	1.8	2.0	17	5	8

Table A-3

CHLORINATION RESULTS

TREATMENT PLANT: Pinole

Date	Detention, Minutes ^a	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #1 : Unchlorinated effluent										
6-12-78								3,300,000	330,000	790,000
6-13-78								1,100,000	330,000	640,000
6-14-78								1,100,000	230,000	410,000
6-15-78								790,000	330,000	595,000
6-19-78								> 240,000	> 240,000	> 240,000
6-20-78								920,000	220,000	450,000
6-21-78								9,200,000	790,000	4,450,000
6-22-78								5,400,000	490,000	1,700,000
6-26-78								7,900,000	1,300,000	4,750,000
6-27-78								7,900,000	2,300,000	4,900,000
6-28-78								13,000,000	2,300,000	4,750,000
6-29-78								7,900,000	1,300,000	2,300,000
Sampling Station #2 : Chlorinated effluent after contact										
6-12-78	48	31.6	26.2	27.9	11.4	4.8	8.5	8	2	5
6-13-78	52	42.3	21.4	39.2	16.0	5.0	10.0	17	< 2	2
6-14-78	43	35.2	30.4	30.8	11.0	4.5	5.5	920	2	43
6-15-78	50	48.0	27.4	34.2	12.0	3.7	6.5	130	5	20
6-26-78	45	36.9	26.4	29.0	12.2	7.6	8.1	1,700	17	640
6-27-78	47	47.1	41.5	45.0	14.4	12.2	13.6	2,400	49	600
6-28-78	52	60+	34.3	45.7	18.2	7.8	12.0	3,500	33	130
6-29-78	52	60+	30.8	47.2	14.5	9.8	10.8	230	13	62
^a Median value, theoretical detention										

Table A-3

CHLORINATION RESULTS (Cont.)	TREATMENT PLANT: Pinole
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Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #2		Chlorinated effluent			after mixing					
6-12-78	2.3	31.6	26.2	27.9	6.8	5.8	6.5 (est.)	5,400	8	280
Sampling Station #3		Pilot plant			after mixing					
6-12-78		20.8	14.7	18.3	6.0	4.5	5.5			
6-13-78		24.4	8.9	16.2	5.1	4.5	4.9			
6-14-78		26.3	8.6	22.8	5.8	4.0	4.6			
6-15-78		27.1	8.6	20.9	5.0	4.0	4.4			
6-19-78		5.8	5.5	5.7	2.0	2.0	2.0	> 24,000	> 24,000	> 24,000
6-20-78		5.5	5.3	5.4	2.4	2.2	2.2	> 240,000	3,300	>200,000
6-21-78		8.0	8.0	8.0	4.0	3.5	3.7	>2,400,000	350,000	>2,000,000
6-22-78		8.6	8.0	8.0	4.0	3.5	3.6	3,500,000	490,000	1,020,000
6-26-78		7.5	7.2	7.5	3.5	3.5	3.5			
6-27-78		8.9	7.2	8.8	4.8	3.6	4.8			
6-28-78		27.7	10.5	24.8	5.8	4.5	4.9			
6-29-78		> 30.5	18.0	27.7	5.0	4.3	4.7			

Table A-3 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Pinole

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4		A: Pilot plant			30 minutes contact					
6-19-78	30	13.9	5.5	5.7				33	8	14
6-20-78	30	5.5	5.3	5.4				330	8	28
6-21-78	30	8.0	8.0	8.0				49	5	23
6-22-78	30	8.6	8.0	8.0				330	33	49
Sampling Station #4		B: Pilot plant			60 minutes contact					
6-19-78	60	13.9	5.5	5.7	4.0	0.8	1.0	≥ 24,000	5	18
6-20-78	60	5.5	5.3	5.4	1.8	1.0	1.2	13	2	8
6-21-78	60	8.0	8.0	8.0	3.5	2.5	2.5	49	5	9
6-22-78	60	8.6	8.0	8.0	2.9	2.2	2.5	49	13	23

Table A-3 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Pinole

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4		E: Pilot plant			15 minutes contact					
6-12-78	15	20.8	14.7	18.3				33	2	13
6-13-78	15	24.4	8.9	16.2				33	5	12
6-14-78	15	26.3	8.6	22.8				33	< 2	9
6-15-78	15	27.1	8.6	20.9				49	< 2	8
6-26-78	15	7.5	7.2	7.5				5,400	110	1,365
6-27-78	15	8.9	7.2	8.8				5,400	79	410
6-28-78	15	27.7	10.5	24.8				1,300	220	330
6-29-78	15	> 30.5	18.0	27.7				490	130	330
Sampling Station #4		F: Pilot plant			45 minutes contact					
6-12-78	45	20.8	14.7	18.3	-	-	-	8	< 2	2
6-13-78	45	24.4	8.9	16.2	4.4	3.5	3.7	8	< 2	< 2
6-14-78	45	26.3	8.6	22.8	4.2	3.4	3.7	8	< 2	2
6-15-78	45	27.1	8.6	20.9	3.7	3.3	3.4	49	2	5
6-26-78	45	7.5	7.2	7.5	2.8	2.0	2.5	330	49	140
6-27-78	45	8.9	7.2	8.8	3.6	2.6	3.5	330	70	130
6-28-78	45	27.7	10.5	24.8	3.8	2.8	3.7	1,300	79	200
6-29-78	45	> 30.5	18.0	27.7	3.4	3.0	3.2	490	23	56

Table A-4 CHLORINATION RESULTS TREATMENT PLANT: South San Francisco

Date	Detention, Minutes ^a	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #1:		Unchlorinated effluent								
8-28-78								49x10 ⁶	3.3x10 ⁶	13x10 ⁶
8-29-78								540x10 ⁶	23 x10 ⁶	205x10 ⁶
8-30-78								920x10 ⁶	49 x10 ⁶	390x10 ⁶
8-31-78								540x10 ⁶	240 x10 ⁶	350x10 ⁶
9-05-78								22x10 ⁶	7.9x10 ⁶	17.5x10 ⁶
9-06-78								140x10 ⁶	7.9x10 ⁶	22.5x10 ⁶
9-07-78								33x10 ⁶	4.9x10 ⁶	11.0x10 ⁶
9-08-78								33x10 ⁶	7.9x10 ⁶	13.5x10 ⁶
9-11-78								540x10 ⁶	46 x10 ⁶	110 x10 ⁶
9-12-78								920x10 ⁶	49 x10 ⁶	>175 x10 ⁶
9-13-78								>2,400x10 ⁶	350 x10 ⁶	>920 x10 ⁶
9-14-78								1,600x10 ⁶	240 x10 ⁶	635 x10 ⁶
Sampling Station #2:		Chlorinated effluent after contact								
8-28-78	28	7.4	3.7	6.4	7.5	2.0		> 240,000	160,000	> 240,000
8-29-78	29	8.4	4.3	4.9	6.0	1.5		240,000	23,000	104,500
8-30-78	31	6.9	3.6	6.5	3.0	0.0		>2,400,000	49,000	>2,400,000
8-31-78	29	8.0	2.4	6.3	1.6	0.0		>2,400,000	240,000	>2,400,000
9-05-78	24	13.1	6.7	9.5	0.0	0.0		>2,400,000	>2,400,000	>2,400,000
9-06-78	27	0.0	0.0	0.0	0.0	0.0		>2,400,000	>2,400,000	>2,400,000
9-07-78	31	8.0	6.4	7.7	4.2	1.2		>2,400,000	800	28,000
9-08-78	25	13.1	2.8	9.1	5.0	2.0		49,000	500	4,900
9-11-78	28	7.4	4.9	6.2	6.0	3.2		79,000	2,300	2,800
9-12-78	30	9.6	2.8	6.6	2.8	0.0		1,600,000	800	26,150
9-13-78	29	7.7	0.0	5.3	3.2	0.0		920,000	<200	5,150
9-14-78	32	10.2	9.2	10.2	5.0	0.4		11,000	500	4,100
^a Median value, theoretical detention										

Table A-4 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: South San Francisco

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #3 B: Pilot plant		after mixing								
8-28-78		13.3	12.2	12.5	8.8	8.4	8.5	>240,000	790	>240,000
8-29-78		14.1	13.0	13.6	9.3	8.0	8.8	>2,400,000	1,600,000	>2,400,000
8-30-78		13.9	11.1	11.9	9.6	7.0	7.4	>2,400,000	23,000	>2,400,000
8-31-78		12.2	10.2	11.5	7.5	4.5	7.0	>2,400,000	1,600,000	>2,400,000
9-05-78		8.0	7.5	7.8	4.2	4.0	4.1	>2,400,000	>2,400,000	>2,400,000
9-06-78		11.9	8.6	8.9	4.8	0.0	4.2			
9-07-78		11.6	10.0	10.7	6.0	2.6	5.0			
9-08-78		10.3	8.9	9.7	4.9	0.0	4.9			
9-11-78		10.3	7.5	9.2	5.0	4.0	4.8			
9-12-78		14.4	10.5	11.2	4.7	0.0	4.1			
9-13-78		10.2	9.4	9.8	4.7	4.9	4.9			
9-14-78		11.1	11.1	11.1	5.4	4.9	4.9			
Sampling Station #4 A: Pilot plant		30 minutes contact								
8-28-78	30	13.3	12.2	12.5	7.4	7.0	7.3	230	< 20	< 50
8-29-78	30	14.1	13.0	13.6	8.0	6.7	7.4	2,300	< 20	< 20
8-30-78	30	13.9	11.1	11.9	8.4	5.7	6.4	20	< 20	< 20
8-31-78	30	12.2	10.2	11.5	6.8	4.2	5.3	270	< 20	20
9-05-78	30	8.0	7.5	7.8	3.2	2.9	3.0	11,000	200	350
9-06-78	30	11.9	8.6	8.9	4.0	3.3	3.7	>2,400,000	200	18,000
9-07-78	30	11.6	10.0	10.7	4.7	1.4	3.8	3,300	20	125
9-08-78	30	10.3	8.9	9.7	4.1	3.3	3.9	330	50	130
9-11-78	30	10.3	7.5	9.2	4.1	3.2	3.8	50	< 20	20
9-12-78	30	14.4	10.5	11.2	3.5	0.4	2.9	> 240,000	230	280
9-13-78	30	10.2	9.4	9.8	4.0	3.5	3.7	50	20	35
9-14-78	30	11.1	11.1	11.1	4.2	4.0	4.2	130	< 20	< 20

Table A-4 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: South San Francisco

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4		B: Pilot plant			60 minutes contact					
8-28-78	60	13.3	12.2	12.5	6.8	6.4	6.6	20	< 20	20
8-29-78	60	14.1	13.0	13.6	7.4	6.0	6.7	50	< 20	< 20
8-30-78	60	13.9	11.1	11.9	7.6	4.8	5.7	330	< 20	< 20
8-31-78	60	12.2	10.2	11.5	6.2	2.0	4.9	790	< 20	50
9-05-78	60	8.0	7.5	7.8	2.6	2.4	2.5	200	200	200
9-06-78	60	11.9	8.6	8.9	3.5	2.6	3.0	1,300	<200	<200
9-07-78	60	11.6	10.0	10.7	4.0	0.2	3.1	1,700	<200	<450
9-08-78	60	10.3	8.9	9.7	3.4	2.8	3.0	7,900	<200	<200
9-11-78	60	10.3	7.5	9.2	3.5	2.7	3.2	50	< 20	< 20
9-12-78	60	14.4	10.5	11.2	4.4	1.0	1.6	92,000	< 20	75
9-13-78	60	10.2	9.4	9.8	4.5	2.7	3.2	20	< 20	< 20
9-14-78	60	11.1	11.1	11.1	5.7	3.3	3.6	20	< 20	20

Table A-5 CHLORINATION RESULTS

TREATMENT PLANT: Sacramento NE

Date	Detention, Minutes ^a	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
<u>Sampling Station #1: Unchlorinated effluent</u>										
10-02-78								1,300,000	330,000	490,000
10-03-78								790,000	< 20,000	490,000
10-04-78								1,300,000	490,000	490,000
10-05-78								1,300,000	230,000	490,000
10-10-78								1,700,000	310,000	790,000
10-11-78								700,000	330,000	395,000
10-12-78								790,000	110,000	410,000
10-16-78								790,000	230,000	490,000
10-17-78								2,300,000	330,000	945,000
10-18-78								790,000	230,000	330,000
10-19-78								1,700,000	330,000	490,000
<u>Sampling Station #2: Chlorinated effluent after contact</u>										
10-02-78	80	11.2	7.8	10.0	10.2	6.7	8.1	5	< 2	< 2
10-03-78	85	15.6	8.0	11.5	8.2	6.2	8.2	2	< 2	< 2
10-04-78	86	15.0	11.2	13.3	10.4	7.7	9.1	2	< 2	< 2
10-05-78	84	12.4	9.1	10.5	9.5	6.7	8.0	23	< 2	< 2
10-16-78	79	9.8	8.2	9.0	9.6	5.8	6.7	13	< 2	< 2
10-17-78	83	12.0	8.5	9.2	8.7	6.1	7.4	5	< 2	< 2
10-18-78	83	11.4	8.7	10.6	8.4	6.4	7.7	5	< 2	< 2
10-19-78	83	10.8	9.3	9.8	8.8	6.8	7.6	5	< 2	< 2
^a Median value, theoretical detention										

Table A-5 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Sacramento NE

Date	Detention, Minutes	Chlorine Dose, mg/l		Chlorine Residual, mg/l		Total Coliform, MPN/100 ml		
		Max.	Min.	Max.	Min.	Maximum	Minimum	Median
Sampling	Station #2A:	Chlorinated effluent		after mixing				
10-03-78	0.2	15.6	8.0	11.5	11.0	> 24,000	< 2	3,900
10-11-78	0.2	10.8	10.0	10.4	10.2	5,000	< 2,000	< 2,000
Sampling	Station #3B:	Pilot plant after mixing						
10-02-78		7.5	6.9	7.0	4.6			
10-03-78		7.5	6.9	6.9	4.8			
10-04-78		7.3	6.7	6.9	4.7			
10-05-78		6.8	5.5	5.8	4.1			
10-10-78		5.7	5.5	5.5	4.5			
10-11-78		5.8	5.3	5.5	4.0	>240,000	54,000	>240,000
10-12-79		2.8	2.6	2.6	3.8	230,000	< 2,000	79,000
10-16-78		6.5	5.7	6.0	1.8	490,000	79,000	200,000
10-17-78		5.7	4.9	5.0	3.9			
10-18-78		4.7	4.0	4.4	3.3			
10-19-78		3.9	3.5	3.7	2.9			
Sampling	Station #4A:	Pilot plant, 30 minutes contact						
10-10-78	30	5.7	5.5	5.5	3.4	50	< 20	20
10-11-78	30	5.8	5.3	5.5	3.3	< 20	< 20	< 20
10-12-78	30	2.8	2.6	2.6	1.0	230	< 20	20

Table A-5 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Sacramento NE

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling	Station #4B	Pilot plant, 60 minutes contact								
10-02-78	60	7.5	6.9	7.0	4.0	3.6	3.7	< 2	< 2	< 2
10-03-78	60	7.5	6.9	6.9	4.1	3.6	3.9	2	< 2	< 2
10-04-78	60	7.3	6.7	6.9	4.7	3.6	3.9	2	< 2	< 2
10-05-78	60	6.8	5.5	5.8	4.3	3.1	3.3	5	< 2	2
10-10-78	60	5.7	5.5	5.5	3.8	3.1	3.2	2	< 2	< 2
10-11-78	60	5.8	5.3	5.5	3.6	2.7	3.2	< 2	< 2	< 2
10-12-78	60	2.8	2.6	2.6	1.3	0.8	1.1	7	< 2	2
10-17-78	60	5.7	4.9	5.0	4.0	2.2	2.4	2	< 2	< 2
10-19-78	60	3.9	3.5	3.7	2.5	1.5	1.8	8	< 2	5
Sampling	Station #4C	Pilot plant, 90 minutes contact								
10-02-78	90	7.5	6.9	7.0	3.7	3.2	3.4	2	< 2	< 2
10-03-78	90	7.5	6.9	6.9	3.8	3.4	3.6	2	< 2	< 2
10-04-78	90	7.3	6.7	6.9	4.6	3.2	3.6	2	< 2	< 2
10-05-78	90	6.8	5.5	5.8	4.3	2.7	3.0	5	< 2	< 2
10-16-78	90	6.5	5.7	6.0	2.8	2.6	2.7	230	< 2	< 2
10-17-78	90	5.7	4.9	5.0	3.8	1.8	2.1	110	< 2	< 2
10-18-78	90	4.7	4.0	4.4	2.8	1.8	2.0	7	< 2	< 2
10-19-78	90	3.9	3.5	3.7	2.6	1.2	1.4	5	< 2	2
Sampling	Station #4D	Pilot plant, 120 minutes contact								
10-16-78	120	6.5	5.7	6.0	2.6	2.3	2.4	5	< 2	< 2
10-18-78	120	4.7	4.0	4.4	2.7	1.4	1.6	2	< 2	< 2

TREATMENT PLANT: Roseville

Table A-6 CHLORINATION RESULTS

Date	Detention, Minutes ^a	Chlorine Dose, mg/l		Chlorine Residual, mg/l		Total Coliform, MPN/100 ml		
		Max.	Min.	Max.	Min.	Maximum	Minimum	Median
Sampling	Station #1:	Unchlorinated effluent						
11-13-78						4,900,000	490,000	2,200,000
11-14-78						3,300,000	700,000	750,000
11-15-78						7,900,000	130,000	410,000
11-16-78						490,000	110,000	280,000
11-20-78						1,300,000	70,000	285,000
11-21-78						230,000	80,000	105,000
11-27-78						7,000,000	330,000	490,000
11-28-78						490,000	20,000	100,000
11-29-78						80,000	20,000	50,000
11-30-78						790,000	20,000	35,000
Sampling	Station #2:	Chlorinated effluent after contact						
11-13-78	99	10.0	8.5	5.4	5.1	2	< 2	< 2
11-14-78	100	9.7	8.7	5.5	4.7	2	< 2	< 2
11-15-78	106	8.3	8.0	5.0	4.9	< 2	< 2	< 2
11-16-78	108	9.8	8.7	5.0	4.8	< 2	< 2	< 2
11-27-78	89	10.9	2.6	5.6	5.1	2	< 2	< 2
11-28-78	110	11.7	10.8	5.5	4.6	2	< 2	< 2
11-29-78	109	16.6	11.5	5.2	3.2	5	< 2	< 2
11-30-78	101	17.6	13.3	4.7	2.4	2	< 2	< 2
^a Median value, theoretical detention								

Table A-6 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Roseville

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling	Station #2A	Chlorinated effluent			after mixing					
11-14-78	0.5	9.7	8.7	9.4	6.2	5.4	5.5	9,200	1,700	3,500
11-28-78	0.4	11.7	10.8	11.1	7.8	5.5	5.9	1,300	200	800
Sampling	Station #3B	Pilot plant, after mixing								
11-13-78		4.6	4.2	4.3	3.4	2.8	3.0	1,700,000 270,000	23,000 50,000	315,000 140,000 330,000 50,000 17,000 3,300
11-14-78		4.6	4.0	4.2	3.2	2.5	2.8			
11-15-78		4.7	3.9	4.1	3.4	2.6	2.8			
11-16-78		4.3	4.2	4.3	2.9	2.8	2.9			
11-20-78		3.0	2.5	2.6	1.2	1.0	1.1			
11-21-78		2.9	2.9	2.9	1.6	1.6	1.6			
11-27-78		4.0	3.9	4.0	2.7	2.5	2.7			
11-28-78		4.6	4.3	4.4	3.2	2.6	2.8			
11-29-78		6.1	5.0	5.5	3.0	2.7	3.0			
11-30-78		6.9	5.4	6.9	3.2	3.0	3.1			

Table A-6 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Roseville

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4A		Pilot plant, 10 minutes contact								
11-20-78	30	3.0	2.5	2.6	0.8	0.6	0.8	24,000	230	8,550
11-21-78	30	2.9	2.9	2.9	1.4	1.3	1.3	330	49	170
Sampling Station #4B		Pilot plant, 60 minutes contact								
11-13-78	60	4.6	4.2	4.3	2.9	2.4	2.7	5	< 2	< 2
11-15-78	60	4.7	3.9	4.1	2.8	2.1	2.2	8	< 2	2
11-20-78	60	3.0	2.5	2.6	0.6	0.4	0.5	16,000	230	1,100
11-21-78	60	2.9	2.9	2.9	1.2	1.0	1.1	79	33	49
11-27-78	60	4.0	3.9	4.0	2.4	2.1	2.2	460	33	130
11-28-78	60	4.6	4.3	4.4	2.8	1.9	2.2	79	23	33
11-29-78	60	6.1	5.0	5.5	2.5	1.7	1.9	23	2	11
11-30-78	60	6.9	5.4	6.9	2.6	1.7	2.1	20	< 2	4

Table A-6 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Roseville

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling	Station #4C:	Pilot plant, 90 minutes contact								
11-13-78	90	4.6	4.2	4.3	2.7	2.2	2.6	2	< 2	< 2
11-14-78	90	4.6	4.0	4.2	2.5	2.0	2.1	2	< 2	< 2
11-15-78	90	4.7	3.9	4.1	2.7	1.9	2.1	2	< 2	< 2
11-16-78	90	4.3	4.2	4.3	2.4	2.1	2.2	2	< 2	< 2
11-27-78	90	4.0	3.9	4.0	2.2	1.9	2.0	490	46	100
11-28-78	90	4.6	4.3	4.4	2.6	1.6	1.8	49	13	33
11-29-78	90	6.1	5.0	5.5	2.3	1.4	1.6	13	< 2	7
11-30-78	90	6.9	5.4	6.9	2.4	1.5	1.8	8	< 2	2
Sampling	Station #4D:	Pilot plant, 120 minutes contact								
11-14-78	120	4.6	4.0	4.2	2.3	1.7	1.9	2	< 2	< 2
11-16-78	120	4.3	4.2	4.3	2.2	1.9	2.2	2	< 2	< 2

Table A-7 CHLORINATION RESULTS TREATMENT PLANT: Dublin-San Ramon

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #1:		Unchlorinated effluent								
4-03-79								54,000	4,600	15,000
4-04-79								33,000	2,000	13,000
4-05-79								33,000	5,000	23,000
4-09-79								130,000	23,000	41,000
4-10-79								110,000	33,000	49,000
4-11-79								110,000	23,000	64,000
4-12-79								79,000	23,000	49,000
4-16-79								49,000	5,000	23,000
4-17-79								49,000	2,000	23,000
4-18-79								33,000	2,000	15,500
4-19-79								13,000	8,000	13,000
4-23-79								33,000	< 2,000	23,000
4-24-79								79,000	22,000	28,000
4-25-79								79,000	13,000	64,000
4-26-79								79,000	13,000	23,000

Table A-7 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Dublin-San Ramon

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #2		Chlorinated effluent			after contact					
4-09-79	47	17.0	14.4	16.3	13.2	6.4	8.6	5	< 2	< 2
4-10-79	53	24.0	20.5	20.7	13.6	11.4	13.0	2	< 2	< 2
4-11-79	51	19.2	15.0	19.0	11.5	9.2	10.5	33	< 2	< 2
4-12-79	54	17.3	12.5	16.4	15.6	7.8	10.9	5	< 2	< 2
4-23-79	53	18.4	8.7	18.0	13.2	6.2	10.8	5	< 2	< 2
4-24-79	64	16.5	13.0	14.2	15.6	5.6	7.2	2	< 2	< 2
4-25-79	43	21.2	17.9	19.1	12.4	8.4	10.9	8	< 2	< 2
4-26-79	73	18.2	0	6.4	10.6	0	5.4	23	< 2	5
Sampling Station #2 A: Chlorinated effluent after mixing										
4-09-79	5	17.0	14.4	16.3	13.3	9.6	11.4	79	23	64
4-10-79	6	24.0	20.5	20.7	17.2	15.6	16.4	49	13	28
4-11-79	6	19.2	15.0	19.0	16.8	10.0	14.4	79	< 2	33
4-12-79	6	17.3	12.5	16.4	18.8	10.0	13.2	49	23	33
4-23-79	6	18.4	8.7	18.0	32.8	11.8	15.3	79	5	49
4-24-79	7	16.5	13.0	14.2	13.6	9.8	10.8	330	49	90
4-25-79	4	21.2	17.9	19.1	18.4	10.2	13.5	130	23	56
4-26-79	8	18.2	0	6.4	12.3	4.4	7.8	13	< 2	13
^a Median value, theoretical detention										

Table A-7 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Dublin-San Ramon

Date	Detention, Minutes	Chlorine Dose, mg/l		Chlorine Residual, mg/l		Total Coliform, MPN/100 ml		
		Max.	Min.	Max.	Min.	Maximum	Minimum	Median
Sampling Station #3	B: Pilot plant after mixing							
4-03-79		11.4	10.3	10.9	8.0	-	-	-
4-04-79		8.0	6.7	7.5	6.0	-	-	-
4-05-79		11.4	10.0	10.7	9.8	-	-	-
4-09-79		14.5	9.0	10.6	9.7	-	-	-
4-10-79		10.8	8.9	10.7	9.2	-	-	-
4-11-79		12.3	11.1	11.5	10.4	-	-	-
4-12-79		12.2	11.5	11.9	10.4	-	-	-
4-16-79		12.1	10.5	11.6	11.6	230	33	95
4-17-79		12.1	11.4	11.6	10.2	490	130	230
4-18-79		8.3	8.0	8.1	6.4	2,400	110	280
4-19-79		8.6	7.8	8.0	6.4	3,500	230	790
4-23-79		12.3	9.8	11.9	10.8	-	-	-
4-24-79		12.6	11.9	12.4	11.3	-	-	-
4-25-79		12.3	11.9	12.0	10.5	-	-	-
4-26-79		12.2	11.6	11.9	10.9	-	-	-

Table A-7 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Dublin-San Ramon

Date	Detention, Minutes	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station # 4A: Pilot plant at 30 minutes contact										
4-03-79	30	11.4	10.3	10.9	6.9	4.8	5.6	79	33	49
4-04-79	30	8.0	6.7	7.5	4.1	2.2	2.8	330	33	230
4-05-79	30	11.4	10.0	10.7	6.9	5.0	5.6	330	49	79
4-09-79	30	14.5	9.0	10.6	5.8	5.0	5.3	130	8	41
4-10-79	30	10.8	8.9	10.7	6.7	6.2	6.4	33	17	23
4-11-79	30	12.3	11.1	11.5	7.5	6.2	7.0	49	17	33
4-12-79	30	12.2	11.5	11.9	7.3	6.5	6.7	33	5	10
4-18-79	30	8.3	8.0	8.1	3.9	3.3	3.7	490	49	75
4-19-79	30	8.6	7.8	8.0	3.8	3.0	3.4	330	33	105
4-23-79	30	12.3	9.8	11.9	7.7	7.0	7.3	33	5	23
4-24-79	30	12.6	11.9	12.4	8.5	7.2	7.5	17	5	8
4-25-79	30	12.3	11.9	12.0	7.1	6.9	6.9	33	13	23
4-26-79	30	12.2	11.6	11.9	8.2	8.0	8.0	5	< 2	3
Sampling Station # 4E: Pilot plant at 15 minutes contact										
4-16-79	15	12.1	10.5	11.6	10.5	7.8	8.3	130	13	33
4-17-79	15	12.1	11.4	11.6	8.6	7.8	8.2	79	8	28

Table A-7 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Dublin-San Ramon

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station # 4B: Pilot plant at 60 minutes contact										
4-03-79	60	11.4	10.3	10.9	4.1	3.2	3.6	49	33	13
4-04-79	60	8.0	6.7	7.5	3.6	1.5	1.2	130	23	33
4-05-79	60	11.4	10.0	10.7	5.7	3.7	4.0	33	17	23
4-09-79	60	14.5	9.0	10.6	4.0	3.4	3.8	33	< 2	10
4-10-79	60	10.8	8.9	10.7	5.2	3.7	4.2	8	2	5
4-11-79	60	12.3	11.1	11.5	5.9	4.2	5.2	5	< 2	2
4-12-79	60	12.2	11.5	11.9	6.2	4.3	5.0	2	< 2	< 2
4-16-79	60	12.1	10.5	11.6	6.1	5.4	5.8	2	< 2	< 2
4-17-79	60	12.1	11.4	11.6	6.2	5.2	5.5	8	< 2	3
4-18-79	60	8.3	8.0	8.1	3.1	2.3	2.5	110	13	49
4-19-79	60	8.6	7.8	8.0	3.2	2.0	2.2	170	33	79
4-23-79	60	12.3	9.8	11.9	6.3	5.0	5.8	8	< 2	3
4-24-79	60	12.6	11.9	12.4	6.6	6.1	6.3	2	< 2	< 2
4-25-79	60	12.3	11.9	12.0	5.7	5.2	5.4	8	< 2	5
4-26-79	60	12.2	11.6	11.9	7.4	6.8	6.8	2	< 2	< 2

Table A-8 CHLORINATION RESULTS

TREATMENT PLANT: Ross Valley

Date	Detention, Minutes ^a	Chlorine Dose, mg/l			Chlorine Residual, mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #1: Unchlorinated effluent										
5-08-79								> 2,400,000	1,600,000	> 2,400,000
5-09-79								3,500,000	490,000	1,300,000
5-10-79								7,900,000	790,000	2,000,000
5-11-79								2,300,000	790,000	1,200,000
5-14-79								13,000,000	1,700,000	3,650,000
5-15-79								7,900,000	1,700,000	3,300,000
5-16-79								11,000,000	2,300,000	3,300,000
5-17-79								7,900,000	2,300,000	3,300,000
5-21-79								13,000,000	2,300,000	3,300,000
5-22-79								7,900,000	500,000	4,900,000
5-23-79								4,900,000	1,300,000	2,800,000
5-24-79								7,900,000	1,100,000	2,800,000
Sampling Station #2A: Chlorinated full-scale effluent, after mixing										
5-14-79	12	14.7	10.2	12.0	8.5	6.2	8.0	35,000	790	24,000
5-16-79	9	14.7	9.3	14.4	11.2	6.8	7.9	3,500	49	1,045
5-21-79	15	34.0	12.0	20.2	15.0	9.0	9.6	490	23	190
5-23-79	15	21.0	9.9	17.0	21.0	9.9	17.0	3,300	20	177
^a Median value, theoretical detention										

Table A-8 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Ross Valley

Date	Detention, Minutes ^a	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling	Station #2:	Chlorinated full-scale			effluent, after contact					
5-14-79	28	14.7	10.2	12.0	9.3	5.0	6.6	> 24,000	23	41
5-15-79	24	15.1	5.8	6.5	8.4	2.6	5.1	- 24,000	5	230
5-16-79	22	14.7	9.3	14.4	9.6	5.3	7.9	79	13	36
5-17-79	25	16.3	4.8	12.1	7.6	4.2	6.4	16,000	13	33
5-21-79	35	34.0	12.0	20.2	10.7	5.8	7.3	70	8	15
5-22-79	24	50.0	11.2	12.9	10.2	6.9	7.4	5,400	5	28
5-23-79	34	21.0	9.9	17.0	10.6	5.7	6.9	79	2	13
5-24-79	26	15.3	7.5	12.4	8.3	4.0	5.6	2,200	7	28
Sampling	Station 3B:	Pilot plant, after mixing								
5-08-79		13.6	13.3	13.5	9.5	9.2	9.3	> 24,000	13	> 24,000
5-09-79		11.5	10.1	10.6	7.9	6.7	7.0	24,000	> 24,000	24,000
5-10-79		7.5	7.3	7.5	4.8	4.6	4.6	2,400,000	240,000	1,250,000
5-11-79		5.1	4.9	5.0	3.0	2.8	2.9	4,900,000	700,000	900,000
5-14-79		6.9	6.2	6.6	4.0	4.0	4.0	-	-	-
5-15-79		6.9	6.5	6.8	4.0	3.9	4.0	-	-	-
5-16-79		6.9	5.5	6.3	4.3	3.6	3.8	-	-	-
5-17-79		6.5	6.1	6.3	4.0	3.7	3.9	-	-	-
5-21-79		7.3	6.9	7.2	4.5	4.2	4.4	-	-	-
5-22-79		6.9	6.6	6.8	4.2	4.0	4.0	-	-	-
5-23-79		6.9	6.7	6.8	4.1	3.9	4.0	-	-	-
5-24-79		6.9	6.8	6.9	4.1	4.0	4.1	-	-	-
	^a Median value, theoretical detention									

Table A-8 CHLORINATION RESULTS (Cont.) TREATMENT PLANT: Ross Valley

Date	Detention, Minutes	Chlorine Dose,mg/l			Chlorine Residual,mg/l			Total Coliform, MPN/100 ml		
		Max.	Min.	Med.	Max.	Min.	Med.	Maximum	Minimum	Median
Sampling Station #4A: Pilot plant at 30 min. contact										
5-08-79	30	13.6	13.3	13.5	8.5	8.2	8.3	23	2	5
5-09-79	30	11.5	10.1	10.6	7.2	6.0	6.2	8	< 2	2
5-10-79	30	7.5	7.3	7.5	4.1	3.8	3.9	49	2	12
5-11-79	30	5.1	4.9	5.0	2.3	2.2	2.2	23	5	11
5-14-79	30	6.9	6.2	6.6	3.4	3.0	3.1	49	5	17
5-15-79	30	6.9	6.5	6.8	3.7	3.0	3.2	49	5	11
5-16-79	30	6.9	5.5	6.3	3.5	2.7	3.0	23	4	13
5-17-79	30	6.5	6.1	6.3	3.0	2.7	2.9	33	2	8
5-21-79	30	7.3	6.9	7.2	3.7	3.5	3.6	33	5	9
5-22-79	30	6.9	6.6	6.8	3.4	3.1	3.2	13	2	8
5-23-79	30	6.9	6.7	6.8	3.3	3.2	3.3	23	2	8
5-24-79	30	6.9	6.8	6.9	3.6	3.1	3.3	13	5	8
Sampling Station #4B: Pilot plant at 60 min. contact										
5-08-79	60	13.6	13.3	13.5	8.3	7.5	7.8	7	< 2	2
5-09-79	60	11.5	10.1	10.6	6.8	5.4	5.8	13	< 2	2
5-10-79	60	7.5	7.3	7.5	3.7	3.4	3.5	23	< 2	8
5-11-79	60	5.1	4.9	5.0	2.0	1.7	1.9	27	< 2	4
5-14-79	60	6.9	6.2	6.6	3.0	2.5	2.6	17	2	5
5-15-79	60	6.9	6.5	6.8	4.2	2.5	2.7	9	2	5
5-16-79	60	6.9	5.5	6.3	3.1	2.3	2.6	8	2	4
5-17-79	60	6.5	6.1	6.3	2.8	2.3	2.6	8	2	5
5-21-79	60	7.3	6.9	7.2	3.3	3.0	3.2	79	< 2	11
5-22-79	60	6.9	6.6	6.8	3.1	2.7	2.8	5	< 2	2
5-23-79	60	6.9	6.7	6.8	3.1	2.5	2.7	8	< 2	2
5-24-79	60	6.9	6.8	6.9	3.2	2.5	2.8	33	< 2	7

Table A-9. CHEMICAL ANALYSES, SAN LEANDRO

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
2-14-78	24.8	14	90.6	960	1260	280	40	38	4.6	9.3	31.5	<.01
2-15-78	15.2	12	84	657	1062	280	32	25	7.0	10.3	< 0.1	<.01
2-16-78	14.7	15	69.7	553	1042	286	30	20	4.8	13.9	0.2	<.01
2-17-78	12.6	20	83.7	652	1100	280	45	38	3.7	18	< 0.1	<.01
2-21-78	14.7	19	76.6	722	--	--	140	102	6.7	30.8	< 0.1	<.01
2-22-78	14.0	14	105	697	--	--	34	25	6.6	20.4	< 0.1	<.01
2-23-78	16.0	21	109	799	--	--	50	23	5.2	17.8	< 0.1	<.01
2-27-78	17.1	17	105	770	1210	300	36	31	5.4	18.6	< 0.1	<.01
2-28-78	18.6	28	109	757	1210	278	54	45	4.7	14.0	< 0.1	<.01
3-01-78	17.3	29	103	747	1120	240	48	41	4.6	9.4	< 0.1	<.01
3-02-78	15.9	21	99.3	686	880	226	51	45	5.0	9.6	< 0.1	<.01

Values in mg/l (except conductivity)

Table A-10. CHEMICAL ANALYSES, SAN PABLO

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
4-10-78	10.5	1.5	39	690	850	204	4	< 1	3.6	< 0.1	22	<.01
4-11-78	11.4	0.7	59	779	950	180	8.5	1	5.5	< 0.1	28	<.01
4-12-78	12.2	2.3	51	1,589	1,030	152	15	< 0.1	2.6	< 0.1	30	<.01
4-13-78	15.2	2.2	55	908	1,050	150	13.5	6	2.6	< 0.1	50	<.01
4-17-78	12.0	3.1	55	1,060	-	125	6	1	0.5	< 0.1	18	<.01
4-18-78	13.4	3.3	82.3	1,051	-	120	7	2	4.6	< 0.1	23	<.01
4-19-78	12.8	3.9	62.6	725	-	120	5	3	2.6	< 0.1	26	<.01
4-20-78	12.1	3.3	66.6	-	-	114	3	2	4.1	< 0.1	40	<.01
4-24-78	10.7	3.5	35.4	-	890	92.5	4.4	< 0.1	2.4	< 0.1	24	<.01
4-25-78	9.6	3.3	43.2	-	1,000	97.5	4	< 0.1	2.1	< 0.1	23	<.01
4-26-78	10.0	5.2	35.4	-	820	100	2.4	< 0.1	1.0	< 0.1	25	<.01

Values in mg/l (except conductivity)

Table A-11. CHEMICAL ANALYSES, PINOLE

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
6-12-78	19	29	47	659	890	94	60	22	4.2	7.7	17.5	1.4
6-13-78	18	17	148	612	923	62	52	16	5.1	12	12	1.9
6-14-78	17	9.2	85.8	700	910	102	52	16	4.3	10.7	12.6	2.5
6-15-78	18	13.5	97.5	646	916	97	32	22	5.8	11.9	12.6	2.6
6-19-78	20.7	20	86.4	600	800	150	9.2	0.8	5.6	16.6	9.6	2.3
6-20-78	18.7	13.5	44.8	595	850	148	16.8	3.6	4.5	17.3	8.0	2.4
6-21-78	19.6	18	128.5	594	910	153	21.7	0.7	6.3	18.7	6.4	2.9
6-22-78	20.6	18	109	583	920	155	15	1.9	9.9	19.6	8.7	1.9
6-26-78	18	14.7	58.4	604	948	141	2	2	4.6	17.7	11.2	1.0
6-27-78	17.2	8	56.8	624	942	129	2	2	4.3	16.6	11.5	1.35
6-28-78	16.3	16.6	59.2	620	922	130	6	6	4.8	12.5	12.6	2
6-29-78	15	14	64.8	600	900	93	10	2	5.3	10.9	13.8	2.9

Values in mg/l (except conductivity)

Table A-12. CHEMICAL ANALYSES, SOUTH SAN FRANCISCO

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
8-28-78	17	22	172	703	1210	215	30.5	20.5	3.1	26.4	< 0.1	<.01
8-29-78	27	48	159	900	1550	275	25	20	8.6	31.4	0.1	<.01
8-30-78	24	33	272	840	1480	215	66.5	37	6.2	27.6	0.3	<.01
8-31-78	27	33	168	814	1495	212	38.4	28.8	6.4	27	0.4	<.01
9-05-78	23	25	117.7	738	1200	123	12	12	11	39.4	< 0.1	0.015
9-06-78	24	26.4	228	968	1680	130	52	48	12.8	30.9	< 0.1	0.01
9-07-78	32	20.5	155	920	1430	125	32	30	11.7	28.2	< 0.1	0.01
9-08-78	32	16	63.5	872	1560	113	26	24.5	16	30.8	< 0.1	<.01
9-11-78	23	76	39.5	712	1350	353	20.5	16	6.6	29.4	< 0.1	<.01
9-12-78	32	176	116	950	1620	312	191	150	8.5	33.5	< 0.1	<.01
9-13-78	29	84	69	923	1550	270	17	8.5	7.9	29.9	< 0.1	<.01
9-14-78	33	100	106.5	976	1800	265	15	13.5	8.8	30.7	< 0.1	<.01

Values in mg/l (except conductivity)

Table A-13. CHEMICAL ANALYSES, SACRAMENTO NORTHEAST

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
10-02-78	10.2	4.7	45.2	300	610	149	3	2	2.6	17.6	0.2	<.01
10-03-78	10.8	8	43.6	309	615	136	4	3	4.4	18.5	0.3	<.01
10-04-78	10.9	7	51.6	309	600	143	7	6	2.7	19.3	0.2	<.01
10-05-78	9.7	9.8	51.2	312	590	144	8	8	3.8	18.6	0.2	<.01
10-10-78	11.8	13	32	312	500	149	11.5	3	3.5	17.4	0.13	<.01
10-11-78	10.4	10	28	313	470	153	3	1	2.9	18.1	< 0.1	<.01
10-12-78	10.9	11.5	32	316	510	158	3.5	1	2.5	18.7	0.13	<.01
10-16-78	11.9	9	51.6	297	700	157	4	4	7.8	15	0.2	<.01
10-17-78	12.0	15.5	70	294	700	159	5	5	4.6	18.6	0.2	<.01
10-18-78	12.0	10	49.2	298	700	156	4	4	3.1	19.2	0.2	<.01
10-19-78	11.9	12	51.6	300	710	180	6	5	4.4	17.7	0.2	<.01

Values in mg/l (except conductivity)

Table A-14. CHEMICAL ANALYSES, ROSEVILLE

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
11-13-78	10.3	6.9	40.0	134	410	114	23.5	22.5	2.1	14.1	1.8	0.02
11-14-78	12.2	5.3	88.0	209	400	103	17.4	14.4	1.6	11.8	1.8	0.32
11-15-78	12.8	7.8	40.0	220	400	100	23.4	20.4	1.8	10.4	1.8	0.08
11-16-78	10.4	3.8	35.2	157	390	93	27.2	24.2	2.0	7.8	2.1	0.31
11-20-78	12.5	18.0	71.6	303	303	105	36.0	35.3	4.4	8.6	1.2	0.22
11-21-78	14.3	13.2	68.4	284	390	109	19.5	19.0	2.7	8.7	0.8	0.51
11-27-78	9.5	66.0	31.4	200	420	95	7.6	6.8	2.9	13.5	1.0	0.1
11-28-78	8.3	7.0	18.4	211	400	85	3.8	2.8	2.0	7.3	3.0	0.98
11-29-78	7.4	2.0	28.8	236	400	80	4.0	2.8	1.5	6.9	3.2	1.5
11-30-78	7.5	5.0	24.8	192	400	80	5.2	3.8	2.1	5.8	3.0	2.2

Values in mg/l (except conductivity)

Table A-15. CHEMICAL ANALYSES, DUBLIN-SAN RAMON

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
4-09-79	8.0	1.2	22.6	858	1260	106	1.2	1.1	1.9	0.5	90	0.12
4-10-79	7.9	0.4	22	777	1250	188	2.0	2.0	1.4	< 0.1	70	0.005
4-11-79	7.8	0.2	22	799	1255	188	2.0	2.0	1.0	< 0.1	66	0.011
4-12-79	11.7	-	21	796	1258	186	0.9	0.9	0.9	< 0.1	64	0.002
4-16-79	8.7	2.0	22	800	1243	202	10.4	1.7	0.9	< 0.1	75	0.006
4-17-79	8.3	0.6	20	809	1268	200	1.0	1.0	1.3	< 0.1	53	0.007
4-18-79	7.8	0.7	20.6	872	1382	206	0.6	0.6	1.4	0.17	50	0.002
4-19-79	8.1	0.5	20.3	866	1390	192	1.1	1.1	1.5	0.3	53	0.002
4-23-79	8.1	0.3	21.4	763	1217	192	2.3	1.1	1.4	< 0.1	66	0.002
4-24-79	7.8	0.8	25.2	833	1343	208	2.5	2.0	1.4	0.07	55.4	0.003
4-25-79	8.2	1.3	25	864	1402	186	1.8	1.4	1.7	0.12	69.1	0.007
4-26-79	9.5	1.0	21.4	771	1240	198	1.2	1.0	1.4	0.12	64.7	0.005

Values in mg/l, except electrical conductivity

Table A-16. CHEMICAL ANALYSES, ROSS VALLEY

DATE	TOC	BOD	COD	TDS	COND	ALK	SS-TOT	SS-VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
5-08-79	11.8	14	105	606	1,050	170	20	13	7.9	19.8	13.3	0.023
5-09-79	12.0	22.5	95.3	579	910	75	29	19	6.5	15.5	16.8	0.114
5-10-79	12.3	21	102	638	1,090	46	34	23.6	8.3	16.9	14.2	0.063
5-14-79	15.0	19	93	1,214	2,050	91	24.4	18.6	8.4	21.0	8.9	0.003
5-15-79	15.5	24	97	1,170	1,930	55	28.6	21.0	9.0	24.4	9.7	0.01
5-16-79	14.9	23	98	718	910	151	31	21.0	8	22.3	10.7	0.01
5-17-79	16.1	23	92.2	757	1,480	162	20	13	4.6	27.3	11.3	<0.001
5-21-79	16.7	26	91.0	949	1,700	108	27	17	8.8	22.9	8.6	0.11
5-22-79	27.2	23	110.4	1,030	1,875	175	25	17	4.1	23	9.2	0.01
5-23-79	16.1	24	132.8	1,258	1,790	160	49	36	3.9	21.9	8.9	0.01
5-24-79	15.1	19.5	104.8	1,303	2,750	191	47	36	4.5	22.8	9.6	0.022

Values in mg/l (except conductivity)

TABLE A-17. AVERAGE CHEMICAL QUALITY OF EFFLUENTS^a

PLANT	TOC	BOD	COD	TDS	COND	ALK	SS- TOT	SS- VOL	ORG-N	NH ₃ -N	NO ₃ -N	NO ₂ -N
San Leandro	16.4	19	99	722	1110	280	42	33	5.3	14.0	< 0.1	< .01
San Pablo	11.8	2.9	53	972	941	132	6.6	1.4	2.9	0.1	28.1	< .01
Pinole	18.2	16	82	620	903	121	23	8	5.4	14.4	11.4	2.1
S. San Francisco	27.0	38	139	860	1494	217	44	34	9.0	30.4	< 0.1	< .01
Sacramento CSD	11.1	10.0	46	305	610	153	5.5	3.8	3.8	18.1	0.17	< .01
Roseville	10.5	7.5	45	215	391	96	17	15	2.3	9.5	2.0	0.62
Dublin-San Ramon	8.5	0.8	22	817	1292	188	2.2	1.3	1.4	0.1	65	< .01
Ross Valley	15.8	22	102	929	1594	126	30	21	6.7	21.6	11	0.03

All values in mg/l, except conductivity

^aArithmetic averages.

Table A-18 TEMPERATURE AND pH DATA^a

Date	Temp ^b	pH ^c					
	°C	Sta. #1	Sta. #2	Sta. #3B	Sta. #4A	Sta. #4B	Sta. #4F
<u>Treatment Plant: San Leandro</u>							
2-14-78	21.1	7.4	7.4	6.7	-	-	8.0
2-15	20.0	7.2	6.9	7.3	-	-	7.6
2-16	20.0	6.6	6.4	6.6	-	-	6.7
2-17	20.0	6.5	6.6	6.4	-	-	6.4
2-21	19.4	6.6	-	6.5	6.5	6.5	-
2-22	20.6	6.3	-	6.3	6.2	6.2	-
2-23	18.9	6.2	-	6.1	6.1	6.1	-
2-24	21.1	6.3	-	6.2	6.2	6.1	-
2-27	20.6	6.6	6.5	6.7	6.7	6.8	-
2-28	21.1	6.6	6.6	6.3	6.3	6.4	-
3-1	21.1	6.6	6.5	6.6	6.6	6.7	-
3-2	21.1	6.3	6.2	6.2	6.4	6.4	-
3-3	21.1	6.8	-	6.8	-	-	-
<u>Treatment Plant: San Pablo</u>							
4-10-78	20.6	6.5	6.5	6.5	-	6.5	
4-11	20.6	6.7	6.6	6.5	-	6.5	
4-12	20.0	6.8	6.8	6.7	-	6.7	
4-13	20.0	6.7	6.7	6.7	-	6.7	
4-17	18.9	6.5	-	6.5	-	6.5	
4-18	20.0	6.6	-	6.6	-	6.6	
4-19	19.4	6.8	-	6.8	-	6.7	
4-20	19.4	6.7	-	6.7	-	6.7	
4-24	20.0	6.7	6.7	6.7	-	6.7	
4-25	20.6	6.9	6.9	6.8	-	6.8	
4-26	21.1	6.7	6.7	6.7	-	6.7	

a. Median values

b. At Sta. #1

c. Sta. #1 - Raw effluent, Sta. #2 - Chlorinated effluent after contact, Sta. #3B - Pilot plant after mixing, Sta. #4A, 4B, & 4F - Pilot plant at 30, 60, & 45 min. contact.

Table A-18 (Cont.) TEMPERATURE AND pH DATA^a

Date	Temp. ^b °C	pH ^c					
		Sta. #1	Sta. #2	Sta. #3B	Sta. #4A	Sta. #4B	Sta. #4F
<u>Treatment Plant: Pinole</u>							
6-12-78	22.8	7.0	7.0	7.0		-	-
6-13	22.8	6.7	6.5	6.6		-	6.6
6-14	22.2	6.3	6.3	6.3		-	6.3
6-15	22.2	6.3	6.3	6.3		-	6.3
6-19	22.2	6.7	-	6.6		6.6	-
6-20	22.8	6.9	-	6.7		6.7	-
6-21	22.8	6.8	-	6.8		6.7	-
6-22	22.2	6.8	-	6.7		6.7	-
6-23	22.8	6.7	-	6.6		-	-
6-26	22.8	6.7	6.7	6.6		-	6.6
6-27	22.2	6.7	6.6	6.6		-	6.6
6-28	21.7	6.3	6.3	6.3		-	6.3
6-29	22.8	6.3	6.1	6.2		-	6.2
<u>Treatment Plant: South San Francisco</u>							
8-28-78	24.4	6.9	6.9	6.9	6.9	7.0	
8-29	23.9	7.0	7.1	7.0	7.0	7.0	
8-30	24.4	6.9	7.0	7.0	7.0	6.8	
8-31	25.0	6.9	6.9	6.9	6.9	6.9	
9-5	25.6	7.1	7.1	7.1	7.1	-	
9-6	25.0	7.1	7.1	7.1	7.1	-	
9-7	25.0	7.2	7.2	7.2	7.2	-	
9-8	25.6	7.2	7.2	7.2	7.2	-	
9-11	25.0	7.3	7.3	7.3	7.3	7.2	
9-12	25.6	7.1	7.1	7.1	7.1	7.1	
9-13	24.4	7.2	7.2	7.1	7.1	6.9	
9-14	25.0	7.2	7.2	7.2	7.2	6.9	

a. Median Values

b. At Sta. #1

c. Sta. #1 - Raw effluent, Sta. #2 - chlorinated effluent after contact, Sta. #3B - Pilot plant after mixing, Sta. #4A, 4B & 4F - pilot plant at 30, 60 & 45 min. contact.

Table A-18 (Cont.) TEMPERATURE AND pH DATA^a

Date	Temp. ^b °C	pH ^c				
		Sta. #1	Sta. #2	Sta. #3B	Sta. #4A	Sta. #4C
<u>Treatment plant: Sacramento NE</u>						
10-2-78	26.1	7.3	7.3	7.3	-	7.3
10-3	25.6	7.0	7.0	7.0	-	7.0
10-4	25.6	7.0	7.0	7.0	-	7.0
10-5	25.0	7.1	7.1	7.1	-	7.1
10-10	25.0	6.9	-	6.9	6.9	-
10-11	25.6	7.1	-	7.1	7.1	-
10-12	25.6	7.1	-	7.1	7.1	-
10-13	25.6	7.1	-	7.1	-	-
10-16	25.0	7.1	7.1	7.1	-	7.1
10-17	24.4	7.2	7.2	7.2	-	7.2
10-18	25.0	7.2	7.2	7.2	-	7.2
10-19	24.4	7.1	7.1	7.1	-	7.1
<u>Treatment plant: Roseville</u>						
11-13-78	19.4	6.9	6.8	6.9		6.8
11-14	17.8	6.9	6.8	6.9		6.8
11-15	17.8	6.9	6.7	6.9		6.8
11-16	18.9	6.9	6.7	6.9		6.8
11-20	17.2	6.9	-	6.9		-
11-21	16.7	7.1	-	7.1		-
11-24	18.9	7.1	-	7.1		-
11-27	18.3	6.9	-	6.9		-
11-28	17.8	6.7	-	6.7		-
11-29	18.9	6.6	-	6.6		-
11-30	18.3	6.6	-	6.6		-

a. Median values

b. At Sta. #1

c. Sta. #1 - Raw effluent, Sta. #2 - Chlorinated effluent after contact, Sta. #3B - Pilot plant after mixing, Sta. #4A & 4C - pilot plant at 30 & 90 min. contact.

Table A-18 TEMPERATURE AND pH DATA^a (cont.)

Date	Temp ^b °C	pH ^c		
		Sta. #1	Sta. #2	Sta. #4B
Treatment Plant: Dublin - San Ramon				
4-03-79	-	-	-	
4-04-79	20.0	-	-	
4-05-79	20.0	7.1	-	6.9
4-09-79	20.0	7.0	6.98	7.0
4-10-79	20.0	7.2		7.2
4-11-79	20.3	7.1	7.1	7.1
4-12-79	20.0	7.05	7.05	7.0
4-16-79	20.3	7.1	-	-
4-17-79	19.7	7.2	-	-
4-18-79	19.7	7.15	-	-
4-19-79	20.0	7.1	-	-
4-23-79	20.3	7.2	-	7.2
4-24-79	20.6	7.2	-	-
4-25-79	21.1	7.2	-	-
4-26-79	20.6	7.15	-	-
Treatment Plant: Ross Valley				
5-08-79	18.2	7.3		
5-09-79	18.4	7.3		
5-10-79	19.2	7.3		
5-11-79	20.0	7.3		
5-14-79	20.0	7.2		
5-15-79	19.5	7.1		
5-16-79	19.2	7.3		
5-17-79	20.0	7.3		
5-21-79	20.0	7.3		
5-22-79	20.6	7.3		
5-23-79	21.2	7.3		
5-24-79	21.2	7.3		

a. Median values

b. At Sta. #1

c. Sta. #1 - Raw effluent, Sta. #2 - Chlorinated effluent after contact, Sta. #4B - Pilot plant at 60 min. contact.